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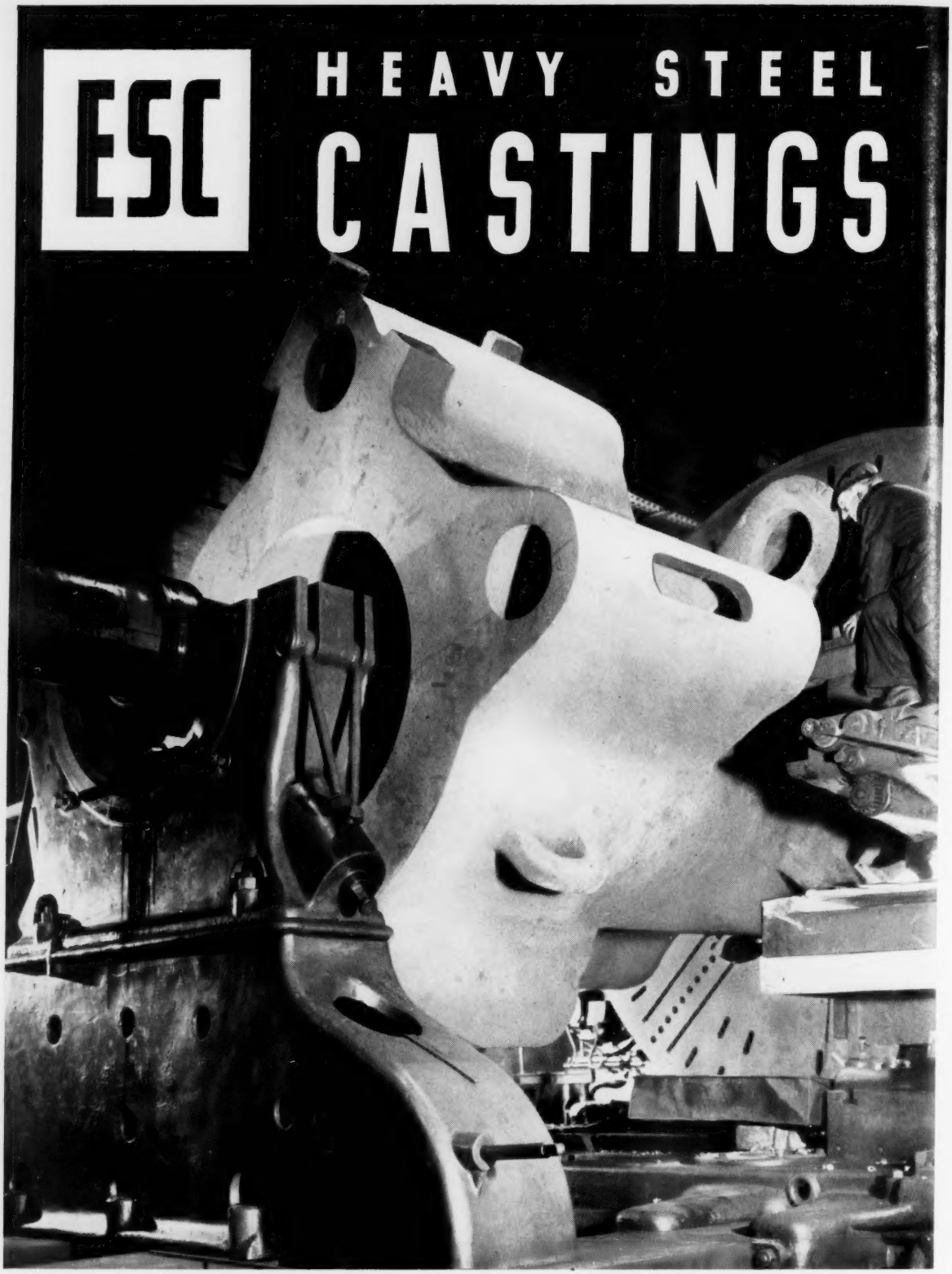

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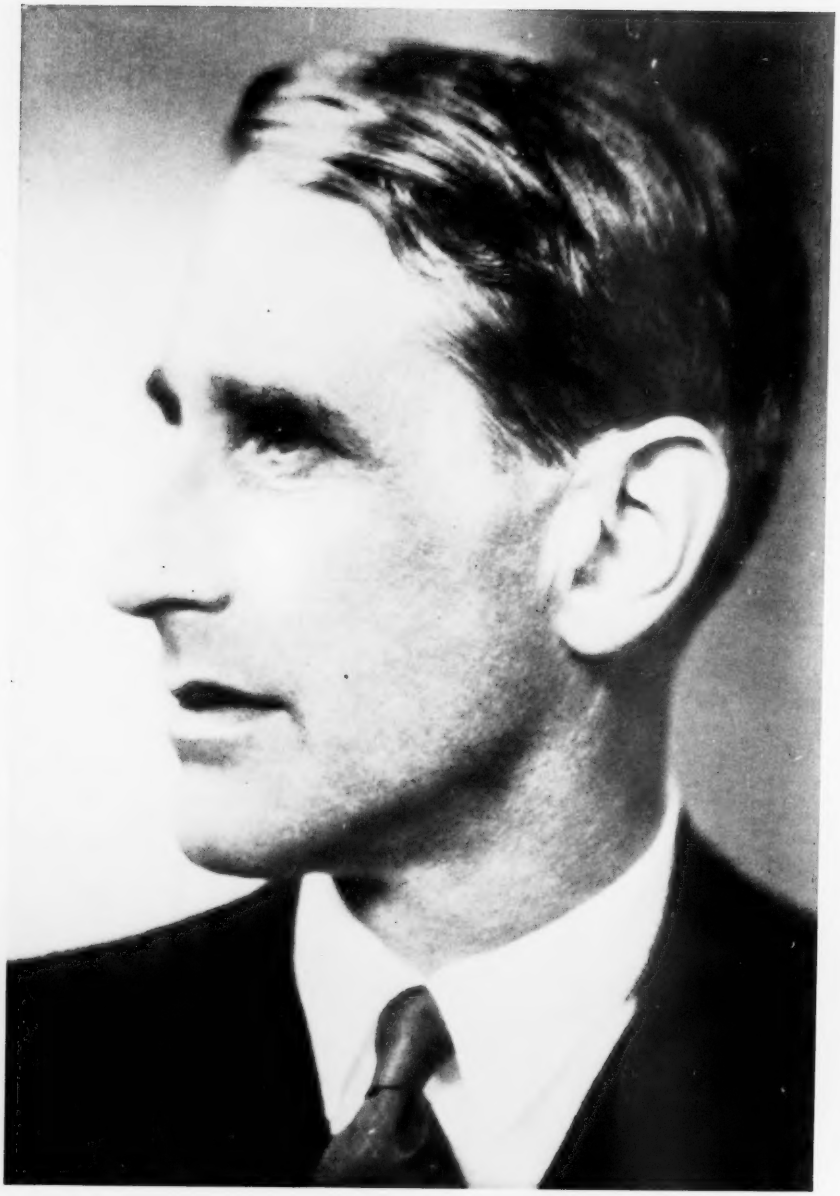
DR. MAGNUS TIGERSCHIÖLD was born in Stockholm in 1893. He studied metallurgy at the Kungliga Tekniska Högskolan, Stockholm, and obtained the degree of Bergsingenjör in 1917.

His first industrial experience was obtained at Trollhättan, but he left that concern after a short time to become assistant to the general superintendent at Söderfors. In 1925 he was appointed superintendent of the open-hearth plant at Fagersta and two years later became superintendent in charge of research for the whole Fagersta combine. In 1936, Dr. Tigerschiöld was appointed Director of Research of Jernkontoret (The Swedish Ironmasters' Association) in Stockholm.

Dr. Tigerschiöld has devoted himself mainly to the development of the methods of manufacture of pig iron and steel, and he is the author of numerous papers on these and related subjects. Most of his papers have appeared in the Jernkontorets Annaler and many have been translated into English and other languages. In 1946 he presented a paper on "Fuel Problems in the Swedish Iron and Steel Industry" at the May Meeting of the Iron and Steel Institute.

In his capacity of Director of Research of Jernkontoret he has been responsible for developing and maintaining relations with corresponding foreign institutions. He has been a member of the Swedish Royal Academy of Technical Science since 1935, and a member of the Swedish Government Board of Technical Research since 1943. In 1945 Dr. Tigerschiöld received the degree of Doctor honoris causa of the University of Upsala.

He has been a Member of the Iron and Steel Institute since 1926, and was awarded the Bessemer Gold Medal in 1947.



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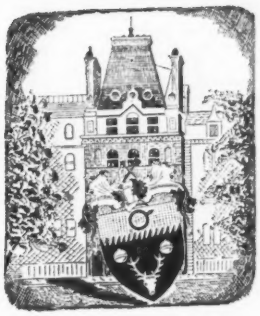


The Iron Ores of Germany*

By A. E. Lance, B.A. (Hons.) Oxon., M.A.I.M.E.†

SYNOPSIS

Descriptions of the iron-ore deposits in Germany, the different types of ore mined, and a general outline of mining methods used are given, accompanied by schedules showing the analysis and classification of the ores, the reserves, and the monthly output for each mine.

SECTION I—INTRODUCTION

THE relative positions of the iron-ore deposits of Germany in the British, French, and American Zones to the centres of the iron and steel industry in the Ruhr and Salzgitter–Peine districts are indicated in Fig. 1. Figure 1 also shows the quantities of ores normally despatched to the blast-furnaces in the Ruhr.

The deposits and the types of ore mined at each deposit are as follows:

Salzgitter, Harz, and Peine	Limonite ($2Fe_2O_3 + 3H_2O$)
Siegerland (upper levels)	Hematite (Fe_2O_3)
Siegerland (lower levels)	Siderite ($FeCO_3$) (spathic iron ore)
Lahn-Dill and Vogelsburg	Hematite (Fe_2O_3) and Limonite ($2Fe_2O_3 + 3H_2O$)
Wesergebirge	Hematite (Fe_2O_3)
Taunus	Siderite ($FeCO_3$) (with an alkaline base)
Baden (dogger ores)	Limonite ($2Fe_2O_3 + 3H_2O$)
Wurtemberg	Limonite ($2Fe_2O_3 + 3H_2O$)
Pegnitz (dogger ores)	Limonite ($2Fe_2O_3 + 3H_2O$)
Amberg	Limonite ($2Fe_2O_3 + 3H_2O$)
Sauerland	Limonite ($2Fe_2O + 3H_2O$)
Harz (Russian Zone)	Hematite (Fe_2O_3)

In the Salzgitter area the ores are an acid limonite, and those in the Peine area are basic.

The ore of the Bülten mine in the Peine district is both manganiferous and self-fluxing.

The ores in the Harz district are mainly basic.

The Siegerland deposits are of manganiferous 'Spateisen' (siderite) with, in some cases, a considerable sulphur content. In the Lahn-Dill area they are mainly a red ironstone hematite, and finally in Baden there are what are known as the dogger ores.

The dogger ores contain a fairly high percentage of lime and have a low iron content. They extend into Bavaria and appear in regular formation at the Pegnitz mine, which is situated to the north of the Amberg deposits. These latter deposits are almost the reverse of the dogger ores, and are, in fact, the richest iron ores in Germany. Their lime content is very low.

In a few cases only it is possible to smelt local ores exclusively. The most important examples are the Ilsede Hütte Works, which smelt their own basic ores, and the Reichswerke, which smelt their own acid ores and manganiferous ores at Peine I/II. Other examples are the Buderus'sche Eisenwerke at Wetzlar, and the Luitpoldhütte Eisenwerke at Amberg which produces foundry iron only, and on a comparatively small scale.

The great bulk of the iron ores must, therefore, be transported over considerable distances. Salzgitter ores and concentrates, for example, were despatched to the Ruhr by the Mittelland Canal—a distance of approximately 200 miles. The bulk of the Harz ores were despatched about the same distance, by rail direct from the mines to the blast-furnaces in the Ruhr. The Siegerland, Sauerland, Lahn-Dill, and Bavarian

* Received 16th December, 1946.

† Metallurgy Branch of the Trade and Industrial Division, Control Commission for Germany.

DESPATCH OF ORES TO RUHR, 1942

Siegerland	942,435
Lahn-Dill and Vogelsberg	594,647
Taunus	152,099
Waldeck	702,066
Thüringen	71,881
Baden-Bayern-Wur ...	998,590
Salzgitter	2,620,020
Total	6,081,738

FIG. 1.—Map showing the main supply sources of iron ore to the Ruhr, of west, central, and south Germany

ores travel by rail, and the Baden ores travel by rail to Kehl and Mannheim on the Rhine, and then on by boat. It has been reported that a large number of the Rhine ore-carrying boats were sunk during the war and that the remainder have been confiscated by the French authorities. On the other hand, it is reported that these boats are being employed in carrying coal from the Ruhr to the French Zone, and it may, therefore, be possible to convey iron ore on their return journey. The Ores and Fluxes panel of the Verwaltungsamt für Stahl und Eisen (V.S.E.) has received instructions to examine the position, and report.

Manganiferous Ores

As manganese is an essential ingredient in the smelting process, the production of iron and steel in Germany is dependent upon the available quantities of this particular type of ore. There are two deposits of these ores ; one in Siegerland and the other in Peine. The main deposit is in Siegerland, and the ores there were normally dressed and roasted at the mines ; only the roasted ore being despatched to the Ruhr. A large proportion of the Siegerland ore body is, however, in the French Zone, and, in addition, considerable quantities were normally obtained from the Fernie mine, in the American Zone. The quantity of manganiferous ores available in the British Zone at present is estimated at only 37,000 tons/month, with an average manganese content of 6–8%. In the French Zone approximately 49,000 tons were mined per month and the manganese content was, with the exception of the Geier mine (18% of manganese), about the same as that in the British Zone. The normal output of the Fernie mine was 7000 tons/month, with a 13% manganese content.

Self-Fluxing Ores

Self-fluxing ores are found in the Harz, Peine, Sauerland, and to a small extent in the Dill, areas. Their lime content means a sacrifice of iron, and, therefore, as mined they are classified as particularly low-grade ores, but when comparatively high-grade ores are averaged with the barren limestone necessary to flux them, the iron content of the resulting ore burden may not be much higher than when using self-fluxing ores.

Hematite Ores

Hematite ores are found in the Dillmulde area and to some extent in the Sauerland. The normal quantity mined was approximately 50,000 tons/month.

Lime Ores

Lime ores can be classified as those which contain more CaO than iron, and there is only one deposit in the British Zone. This deposit is in the Wesergebirge district, near Minden. The quantity of ore mined monthly averaged 100,000 tons.

The schedules of available ores in Germany are shown in Tables III–V, VII–XII, XIV, and XXIII, with the analyses of the ores from each mine, and the classifications of the ores in the French, American, and British Zones. They will, it is hoped, provide the information necessary for formulating furnace burdens.

Each of the main iron-ore deposits, as indicated in Fig. 1, is dealt with separately in this report, in which particulars of the ore bodies, mining, and ore-dressing statistics are given. Technical details of the mine workings and ore dressings have been purposely omitted. A separate report on these will follow later.

Section II—Salzgitter, Harz, and Peine Deposits

Salzgitter Ores

The Salzgitter ores are of an oolitic limonite, high in silica and with considerable quantities of clay in the matrix. There are two classes ; the brown, and the red deposits. The red deposits rest on the brown deposits with or without intermediate matter, and are a fairly soft ore. They are worked at the Haverlahwiese, Hannoversche Treue, Wortlah, Ohlendorf, and Fortuna mines, and in the southern part of the Finkenkuhle mine. The brown deposits are worked at the Gitter Georg, Ida, and Morgenstern mines, and they are as a rule harder, and are marked in almost all cases by a higher lime content. The Salzgitter deposits are, however, comparatively low in lime as compared with the brown iron ores. The brown deposits do not differ to any great extent in their structure and petrographical development from the red deposits.

The Salzgitter area has been folded by lateral pressures, into rows of anticlines and synclines striking west-south-west to east-north-east, and it is in the synclines or basins that the ore sediments are concentrated. There are two rows of anticlines, and the core is formed in both cases by salt domes which have partly pushed their way through to the surface.

The ore deposits in this district are massive and it is therefore possible to mine large tonnages within a comparatively small area.

Production

The acid-ore mines of the Salzgitter district, their normal and maximum output, and the analyses of the raw ores are shown in Table I.

The Haverlahwiese, the Hannoversche Treue, and the Finkenkuhle mines have both open-cast and underground workings. The Morgenstern mine is open-cast, and the Fortuna, Ida, and Gitter Georg are underground mines.

TABLE I—*Output and Analysis of Ores from the Mines of the Salzgitter District*

Mine	Output per Day, tons		Analysis						
	Normal	Maximum	Fe, %	CaO, %	SiO_2, %	Al_2O_3, %	MgO, %	Mn, %	P, %
Haverlahwiese	10,600	21,000	30–33	5·0	24·0	8·0	1·3	0·3	0·4
Hannoversche Treue	3500	6000	30	5·0	22·0	9·0	2·0	0·2	0·4
Wortlah, Ohlendorf	1000	2000	28	5·0	26·0	9·0	–	–	0·4
Finkenkuhle	2500	4000	28	5·0	26·0	8·0	2·3	0·2	0·4
Fortuna	1200	1400	29	3·0	22·0	8·0	1·45	0·2	0·57
Gitter Georg	2500	5000	27	7·0	27·0	9·0	1·3	0·2	0·4
Ida	800	1000	25	3·0	22·0	6·78	1·94	0·2	0·7
Morgenstern	500	600	28	3·0	22·0	6·74	2·0	0·7	0·47

The normal output of the Reichswerke mines alone was, as will be seen, 20,000 tons/day or 6,000,000 tons/year. The maximum output for this district was reached in May and June, 1940, when the output was 36,000 tons/day, or at approximately 10,800,000 tons/year.

All of the acid-ore mines are equipped with the most modern plant and machinery. They are mechanized throughout with labour- and time-saving devices. The Reichswerke mines alone could produce up to 10,000,000 tons of ore per year.

Ore Dressing

The low-grade soft ores from the Haverlahwiese and Hannoversche Treue mines, which amount to approximately 14,100 tons/day, contain as already indicated, a fairly high percentage of clay, and 4800 tons/day of these lower grades are crushed, screened, and either washed or despatched to the Lurgi plant before being sintered at the steelworks. The Fortuna, Ida, and Morgenstern mines wash all their own ores, and the concentrates only are despatched to the Ruhr.

The results obtained by washing the Salzgitter ores are shown in the Table II.

Labour

The number of surface workers and miners employed at the Reichswerke mines, in 1945, was 6750, of which 2230 were foreigners and 790 were Prisoners of War. The mines had accommodation for 6000 workers. At present the camps are occupied by Displaced Persons. At the Vereinigte Stahlwerke, A.G. (Vestag) mines 1037 workers were employed, and all were accommodated in mine houses at or near the mines.

The labour problem in the Salzgitter district is acute. The great bulk of the miners are at present working, under agreement with the mines, on clearing away debris in Brunswick, Hannover, and Hildesheim, and on the reconstruction of

TABLE II—*Salzgitter Ore Preparations*

Mine	Output per Day, tons	Production	Crushing and Screening		Washed Ore, %	Fe Content, %	Fe Content at Lurgi Plant, %	Fe Content at Renn Plant, %
			Wt. of Ore, %	Fe Content, %				
Haverlahwiese	20,000	Raw ore	100	33·6	Raw ore	27·2	28	26·7
		Fines, 0–22 mm.	80	35·4	Concentrates	38·1	42	—
		Large pieces	20	26·5	Tailings	14·0	14	3
Hannoversche Treue	20,000	Raw ore	100	30·5				
		Fines, 0–20 mm.	80	31·7				
		Large pieces	20	25·7				
Fortuna		Raw ore	—	—	Raw ore	30		
		Fines	—	—	Concentrates	37		
		Large pieces	—	—	Tailings	—		
Ida	1200	Raw ore	—	—	Raw ore	25		
		Fines	—	—	Concentrates	37		
		Large pieces	—	—	Tailings	—		
Morgenstern	600	Raw ore	—	—	Raw ore	29		
		Fines	—	—	Concentrates	35·7		
		Large pieces	—	—	Tailings	—		

TABLE III—*Schedule of Iron Ores from the Peine and Salzgitter Districts (British Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening. Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Peine	Ilseder Hütte	Bülten ...	35,000,000	75,000	35,000 (target 50,000)	L, < 40 M, 40–8 F, 8–0·8	R, 100 L, 26 M, 16 F, 58	26·38 22·53 22·04 20·67	2·95 2·97 3·91 2·80	22·02 28·15 26·15 16·93	8·85 4·86 5·69 12·20	2·46 1·97 2·26 2·63	0·86 0·81 1·13 0·87	1·84 1·64 1·67 1·75	223,108	Crushing and Screening plant at the mine. Raw ore despatched direct to blast-furnace. Underground workings
		Lengede ...	19,000,000	50,000	16,000 (target 25,000)	L, < 8 M F, 8–0·48 C	R, 100 L, 20 F, 80	27·65 34·04 38·91	0·34 0·36 0·37	14·10 16·96 13·82	12·85 9·06 7·75	3·38 2·83 2·32	1·53 1·93 1·33	1·23 1·13 1·10	59,712	Crushing, Screening, and ore-dressing plant at the mine. Underground workings
		Dornten ...	6,000,000	8000	Nil	L M F	R, L, F,	29·05	0·24	5·84	25·14	6·70	0·57	2·72	15,000	No crushing, screening, or dressing plant at the mine. Ore is screened at the mills, along with Salzgitter ores, *etc.* Mills take 15–20% of Salzgitter ores. 45–50% from Bülten, 30–35% from Lengede, and 15–20% from Salzgitter Open-cast mine.
Salzgitter	Reichswerke...	Peine I/II ...	60,000,000	30,000	Nil (target 13,000)	L * < 11% M F, > 11%	R L F	23·00	2·00	22·00	8·00		1·00		33,482	Mine undergoing shaft repairs. Raw ore normally despatched to smelters. No crushers, screeners, or dressing plant
		Haverlahwiese I ...		100,000	10,000 (target 50,000)	L, < 11%† M F, > 11%	R, 100 L, 20–30 F, 40–80	33·50 26·50 35·40	0·17 0·15 0·18	4·80 6·70 4·30	22·8 28·4 20·5	8·60 10·20 8·20	0·44 0·46 0·45	1·20 1·20 1·20	9549	Central crushing and dressing plant at Calbecht. No screening plant. Capacity of Calbecht plant, 3600 tons of raw ore/day. Only Haverlahwiese and Hannoversche Treue ores of below 28% of Fe are dressed. Underground workings. 25% of ore production treated by Lurgi process
							C (wet) C (Lurgi)	38·10 42·00	0·20 0·21	5·50 5·00	14·20 19·00	7·60 8·90	0·55 0·412	1·70 2·50		Capacity of Lurgi plant at Watenstedt, 5600 tons/day
							C (sintered)	41·00	0·27	6·70	23·30	9·00	0·50	1·90		Capacity of sintering plant 4800 tons/day; each band, 1200 tons/day‡; 8 bands, 4 working. 15% of moisture in the wet concentrate. Only the ores and concentrates are sintered Underground workings

* Screening Sizes : L = > 50-mm. ring ; M = < 50, > 15-mm. ring ; F < 15-mm. ring.
† Ore crushed and screened at the Reichswerke mill. Screening capacity 15,000 tons/day. Crushing capacity 30,000 tons/day
‡ When operating for supplies . . . ore for the Ruhr, the bands must travel slowly and the capacity is reduced to 800 tons/day.

TABLE IV—*Schedule of Iron Ores from the Salzgitter District (British Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946 tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Salzgitter ...	Reichswerke...	Haverlahwiese II		40,000	...	L, > 11	R, 100	28·00	...	4·00	31·00	8·50	0·35	1·30	(included in Haverlahwiese I)	Central crushing, screening, and wet ore dressing plant at Calbecht (see Haverlahwiese I). Capacity 7200 tons/day. Underground working
					Target 20,000	M F, < 11	L, 20 F, 80 C (wet) C (sint.)									
		Haverlahwiese (open-cast)	(Reichswerke mines) 1000 million to 2000 million	125,000	Target 70,000	L, > 11 M F, < 11	R, 100 L, 20 F, 80 C (wet) C (Lurgi) C (sint.)	30·00	...	5·00	24·00	8·50	0·42	1·30		,,
		Finkenkuhle...		62,500	14,000 (target 25,000)	L >11 M F, < 11	R, 100 L, 20 F, 80 C (wet) C (sint.)	27·00	...	5·00	28·00	7·00	0·41	2·30		Open cast ,,
		Gitter Georg...		62,500	Nil (target 25,000)	L, > 11 M F, < 11	R, 100 L, 40 F, 60 C (wet) C (Lurgi) C (sint.)	26·00	...	5·00	30·00	9·00	0·40	2·00	Nil	Open and underground working. 100% of ore production treated by Lurgi process ,,
		Hannoversche Treue... ...		87,500	25,000	L, > 11 M F, < 11	R, 100 L, 20 F, 80 C (wet) C (Lurgi) C (sint.)	30·50 25·70 31·70	0·46 0·19 0·15	5·80 7·10 5·50	23·90 26·80 22·30	8·90 9·90 8·60	0·39 0·45 0·38	2·00 2·30 1·90	2633	100% of ore production treated by Lurgi process. Underground working ,,
		Worlah ...		25,000	Nil (target 15,000)	L M F	R L F C (wet) C (Lurgi) C (sint.)	28·00	...	5·00	26·00	...	0·40	...	65,200	Ore is soft and very suitable for wet dressing. Open cast and underground workings No crushing, screening, or ore dressing plant. Deep mine, hard ore; dressing only suitable for Renn plant; the clay lands contain too much iron. Underground workings

railways and the Mittelland Canal. By this agreement the miners are permitted to return to the mines when they are reactivated, but it is feared that many of them will not do so, preferring to carry on with their present work. The best, and probably the only enticement would be to offer them a considerable increase in their wages. A number of these miners have also been recruited for work in the Ruhr coal mines, and although they would be glad to return to their own mines they may not be allowed to do so. The miners at present receive the same rate of pay as the surface workers, and in some cases less, *i.e.*, there is no inducement for a young man to work underground, and as a direct consequence there are very few young men in the mines today. This question shall be carefully investigated, and reported upon later.

Despatch

All of the Salzgitter mines are equipped with modern loading devices, and the Reichswerke have 500–600 specially constructed 65-ton iron-ore waggons by which the ores can be rapidly loaded and discharged, and 75 locomotives. The steelworks also have specially-designed barges and tugs for the transport of ores and coal on the Mittelland Canal. Each barge has a capacity of 125 tons of ore, and one train consisted of 24 barges with one tug ahead and another behind. The whole train-

TABLE V—*Schedule of Iron Ores from the Harz District (British Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946 tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Harz	Vestag ...	Fortuna ...	6,000,000	30,000	9000 (target 20,000)	L, > 8 F, < 8	R, 100 L, 60 F, 40 C	29·00 36·00	0·30 0·30	3·00 5·20	28·50 18·50	9·26 6·02	0·44 0·57	1·74 2·50	23,000	Crushing, screening, and wet ore-dressing plant at the mine. Wet concentrates contain 15% of moisture but when despatched approx. 8%. Underground workings
		Morgenstern	4,300,000	12,500	Nil (target 10,000)	L, > 8 M F, < 8	R, 100 L, 40 F, 60 C	28·00 36·00	0·20 0·30	3·50 5·20	30·00 18·50	6·74 6·02	0·50 0·57	2·00 2·50	6883	Open cast workings. Crushing, screening, and ore-dressingplant at the mine. Percentage of C to R 65-wt.-%
		Ida	1,800,000	20,000	4500 (target 10,000)	L, > 8 M F, < 8	R, 100 L, 40 F, 60 C	25·00 35·60	0·30 0·22	5·43 4·80	27·00 17·50	4·00 7·00	0·37 0·55	... 2·50	Nil	Crushing, screening, and wet ore-dressing plant at mine. Percentage of C to R, 50–55 wt.-%. Undergrounds workings
		Barbecke	2,750,000	17,500	2000 (target 10,000)	L, > 8 M F, < 8	R, 100 L, 40 F, 60 C	25·80 36·00	0·35 0·40	19·00 14·50	14·80 7·50	2·80 5·00	1·85 1·40	1·20 1·50		Underground shallow workings, incline shafts. Crushing, screening, at mine. Raw ore despatched to Ruhr. C, analysis by test sample of 20 tons
		Ernst August	300,000	8750	Nil (target 5000)	L, > 8 M F, < 8	R, 100 L, 80 F, 0 C, ... of raw ore	21·00	0·20	20·00	16·00	8·76	0·40	2·00	Nil	Open cast workings, Raw ore normally despatched to the Ruhr, no crushing or ore-dressing plant at the mine
	Krupp ...	Echte ...	30,000,000	50,000	7000 (target 25,000)	L, ... M, ... F, ...	R, 100 L, ... F, ...	22·00	0·21	18·00	15·00	...	0·40	...	140,993	No crushing or ore-dressing plant at the mine. Raw ore despatched to Ruhr. Underground workings
		Hansa ...	3,750,000	10,000	3000 (target 8000)	L, ... M, ... F, ...	R, ... L, ... F, ...	22·00	0·21	23·00	9·00	...	0·40	...	96,620	,,
		Friederike ...	3,250,000	12,500	3200 (target 8000)	L, ... M, ... F, ...	R, ... L, ... F, ...	26·70	0·21	18·00	12·00	...	0·40	...	23,549	,,
	Mannesmann	Steinberg ...	1,000,000	5000	440	L, ... M, ... F, ...	R, ... L, ... F, ...	20·00	0·13	17·00	19·00	...	0·40	...	40	No crushing or screening plant at the mine. Raw ore despatched to Ruhr. Open-cast workings
		Marie Caroline ...	200,000	5000	911	L, ... M, ... F, ...	R, ... L, ... F, ...	32·00	0·70	6·50	17·00	9·50	0·60	1·90	Nil	,,

load can be unloaded in 2 hr. Each barge is lifted bodily out of the water and is emptied into bins.

In view of the large tonnages which can be mined in this area, the rail connections between the mines and the steelworks on the Mittelland canal, and the modern loading and discharge arrangements, every consideration should, in the author's opinion, be given to the possibility of using these ores to the maximum extent. Further, in the immediate neighbourhood, *i.e.* in the Harz and Peine districts, there are considerable quantities of basic ores available. The majority of the mines here are also equipped with modern plant and machinery, and the author suggests finally, that in view of the present transport difficulties, consideration be given to the sintering of all ores at the steelworks before despatch to the Ruhr. The ores and concentrates could be transported from the mines by rail to the steelworks, treated there, and the sintered ore shipped to the Ruhr *via* the Mittelland Canal. Formerly, the Vestag mines transported washed ore containing up to 20% of moisture.

Particulars of each mine are shown in Tables III and IV.

Harzvorland Ores

The Harzvorland deposits are of a basic brown ironstone (limonite) with varying degrees of clay in their composition, and containing on an average approximately 18% of CaO. The mines in the area are as follows :

Mine	Owner
Echte, Hansa, Friederike	Krupp, A. G.
Ernst August	Vestag
Marie Caroline, Steinberg	Mannesmann

The Echte, Hansa, and Friederike are underground mines; the Marie Caroline and the Steinberg are small open-cast workings.

The Echte mine was opened during the war, and is fully mechanized throughout with the most modern plant and machinery. The Hansa and Friederike mines are small, and although well planned they are not modern.

The raw-ore output from all six mines in this district was transported direct from the mines to the Ruhr, *i.e.*, there are no ore-preparation plants at any of the mines.

The analyses of the ores from each mine and other particulars are shown in Table V.

The Peine Ore Deposits

The Peine or Upper Emscher ore deposits cover the area bordered on the west by a line between Schwiechelt and Adenstedt, on the east by a line through Broitzen and Immendorf, on the south by the Lichtenberg hills, and on the north by a line between Stederdorf and Woltorf.

The mines included in this area are the Bülten and Lengede of the Ilseder Hütte, A.G., Peine I/II, belonging to the Reichswerke, and Barbecke of the Rohstoffbetriebe Vereinigte Stahlwerke.

The deposit is a detrital formation, and the rubble consists of a brown phosphoric ironstone varying in size from a 1-in. to a 6-in. ring. These are embedded in the upper portion in clay, and in the lower section in marl.

Owing to a later folding of the beds, the deposit is divided into five sections as follows :

(i) Peine basin—Peine I/II mine
(ii) Ilse Oedesser anticline —Bülten mine
(iii) Lengede basin—Lengede mine
(iv) Egelnstedt Hillerse anticline—Barbecke mine
(v) Ufinger basin

The ores in the Ufinger basin are poor and not profitable to work.

The ores in the Peine basin and the Ilse Oedesser anticline are manganiferous and are also self-fluxing, containing on an average, 2% of Mn, 22–23% of CaO, and 7–8% of SiO_2. Those in the Lengede basin and the Egelnstedt anticline are basic ores containing very little manganese, 27–28% of Fe, and 18% of CaO. The analyses of these ores, the quantities mined, and other particulars are shown in Table III.

TABLE VI—*Schedule of Analyses of Washed Ore by Sizes*

Classification	Grading, wt. %	Analysis								
		Fe, %	SiO_2, %	CaO, %	Mn, %	P, %	S, %	MgO, %	Al_2O_3, %	Loss, %
Raw ore	100	32·10	13·60	15·6	0·45	1·31	0·1	1·31	3·13	16·98
Fines	60–65	42·00	6·86	11·5	0·48	1·57	0·06	1·02	1·95	14·26
Large pieces	30–25	39·10	6·50	13·99	0·42	2·60	0·09	1·22	3·04	12·72
Waste	10									

Ore Preparation

The results obtained by the ore-preparation plant at Lengede, in which the whole output is washed, are tabulated in Table VI, and as follows :

Moisture in the raw ore	...	8–10%
Moisture in the washed ore	...	15–20%
Normal output of the plant	...	2000 tons/day
Maximum capacity of the plant	...	3000 tons/day

The Barbecke ore was despatched to the Ida ore-dressing plant, and the washed ore, along with the Ida ore, was despatched to the Ruhr.

The bulk of the Lengede washed ores were sintered at the steelworks at Gross Ilsede. An average cost of washing was 1·15 reichmarks.

Section III—Siegerland Manganiferous Iron Ores

Ore Body

The Siegerland deposits of iron ores are of spathic ironstone ($FeCO_3$) with approximately 30% of Fe and from 4 to 5% of Mn. They are the main source of manganiferous ores in Germany, and a further feature of importance is that they are practically free of phosphorus.

The raw ores are of iron carbonate mixed with considerable quantities of manganese carbonate. There is also quartz, pyrites, and cuprous gravel in the gangue. For this reason the whole of the output from the mines is crushed, screened, dressed, and roasted at the mines before being despatched to the Ruhr. This processing of the raw ores results in a saving of approximately 30% by weight, and the iron content is raised to 48–51% and the manganese content to 8·5–11%.

The ore bodies are in the form of lenticular veins. They appear in the cracks of the rocks, which dip almost vertically.

The present workings are at depths ranging from 3000 to 4000 ft., and the veins measure, on an average, approximately 6 ft. in thickness, though some are actually 30 ft. thick. They are also highly faulted and distorted.

Mining Methods

It is evident that mining operations are extremely difficult and costly. Modern methods of ore extraction and transport underground cannot be applied as the mines are old and the working faces are widely scattered and broken.

A significant feature throughout the Siegerland mines is the adaptation of methods to fit conditions. Every factor involved has been carefully studied, mainly with a view to lowering the costs.

Labour

As will appear to be evident, the miners must be specially trained and highly skilled at their work. Silicosis is unfortunately prevalent throughout the whole area and for this reason young men are not willing to serve an apprenticeship underground. Considerable difficulties are therefore experienced in getting the miners to return to the mines and in recruiting fresh labour.

In addition, a large number of the miners live in the British, American, and French Zones, and arrangements will have to be made for them to pass freely to and from the mines.

The scarcity of miners in the district is a very serious matter and in order to obtain the required output of ores it is suggested that :

(*a*) Capable miners now employed in other industries should be released and induced to take up mining again.

(*b*) Young men should be placed at the disposal of the mines for training.

(*c*) Miners living in the French and American Zones, who were normally employed in the mines in the British Zones should be allowed to cross the boundary freely, and that suitable transports should be arranged to take them to and from the mines.

(*d*) Metal miners now employed in the coal mines should be allowed to return to the iron mines.

(*e*) Additional food and clothing should be provided for all miners. The supply of clothing and boots will become an urgent necessity. Normally the mines supplied both.

To obtain the normal output, about 3300 miners are required in the British Zone and about 6500 in the French Zone. At present there are about 1500 miners at the mines.

Production

In the British Zone there are 5 mines, 4 of which belong to the Rohstoff Vereinigte Stahlwerke, A.G., and the fifth is owned by Glockner, A.G. The normal output was 65,700 tons/month. For the first year after reactivation it is not likely to exceed 30,000 tons/month.

In the French Zone there are 8 mines with a total normal output of 104,750 tons/month. The estimated output under present conditions for a period of 1 year is at the rate of 50,000 tons/month.

Stocks of Ores at the Mines

The total stocks of ores at the mines in the British Zone are estimated at 33,730 tons of raw ores and 25,410 tons of roasted ores, and in the French Zone, 86,000 tons of raw ores and 59,648 tons of roasted ores.

Ore Reserves

The records of the mines, their ore reserves, the normal and estimated present output, the stocks at each mine, and the analysis of the ores, are shown in Tables VII and VIII.

Ore Dressing

In addition to the sulphurous pyrites, copper, zinc blende, and galena in the ore body, there

TABLE VII—*Schedule of Ores from the Siegerland District (British Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening. Sizes. mm.	Ore Classification. %	Analysis of Ores							Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	Cu, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Siegerland ...	Vereinigte Stahlwerke, A.G.	Eisenhardter Tiefbau	418,000	11,000	1200	L, 150–40 M, 40–20 F, < 20	R, 100 L, 19 F, 6 C, 25 RO/I } 75 RO/II }	32·50 34·40 36·00 50·65 42·43	6·00 6·49 6·70 9·31 7·47	0·20	14·00 7·58 4·00 6·50 20·75	1·00	0·01	2·50	1153 ... 255	Crushing, screening, dressing and roasting at the mine. Underground workings
		Neue Haardt	605,000	18,000	Nil (target 10,000)	L, 170–100 100–42 M, 42–22 F, < 22	R, 100 L, ... F, 30 C, ... RO/I } 75 RO/II }	32·00 38·61 36·60 50·39 44·38	4·80 4·46 6·70 8·67 7·91	1·20	18·00 13·09 6·50 8·74 15·81	1·21	0·01	2·30	4782 1506	Repairs in hand. Production in 3 months. Crushing, screening, dressing and roasting at the mine
		Grosse Burg	280,000	5000	Nil (target 2000)	L, 120–40 M, 40–20 F, 20–10	R, 100 L, ... F, 75 C, 75 RO/I } 25 RO/II }	30·00 32·50 32·50 48·40 43·00	6·50 6·50 6·50 9·70 8·80	0·45	16·00 10·50 12·50 11·00 17·00	1·50	0·01	2·06	245 6783 from flotation 1254	Lower levels flooded. Work stopped for the present. Miners sent to Eisenhardter Tiefbau. Crushing, screening, dressing, and roasting at mine. Moisture content of ore from flotation plant, 14 wt.-%
		Eisenzecher Zug	239,000	16,700	1000 (target 8000)	L, 200–60 M, 40–24 12–24 F, < 12	R, 100 L, ... F, ... C, 19 RO/I } 81 RO/II }	30·40 31·44 34·00 48·00 41·28	6·80 7·15 7·80 10·79 9·30	0·60 ... ... 0·50 0·60	15·80 10·09 6·70 14·40 20·57	0·48	0·01 0·01 ... 0·01 0·01	2·90	3316 1001	Crushing, screening, dressing, and roasting at mine
	Klückner and Vereinigte Stahlwerke, A.G.	Pfannenberger Einigkeit	680,000	15,000	Nil (target 8000)	L M F	R, 100 L, ... F, ... C, 18 RO/I } 82 RO/II }	36·34 33·40 48·50	6·79 6·31 9·00	0·10	6·41 10·51 9·00	2·54	0·002	0·632	3492 6155	Crushing, screening, dressing, and roasting at the mine

are silicious acids and alum which percolate the gangue in the quartz and country rock. These impurities and admixtures of metals make ore dressing an essential factor in the separation of the iron-bearing ore.

As will have been seen there are considerable variations in the ores which necessitate differences in the methods of treatment. The general system of ore dressing can be described as follows. The raw ore is crushed and screened and the particles of size greater than a a 30-mm. ring are hand picked. Those of size less than a 30-mm. ring are mechanically washed and dried, and in some cases the iron-bearing particles are extracted by magnetic separation. The dressed ores are then roasted in simple shaft furnaces in which the carbon dioxide is expelled. A great deal of the sulphur contained in the ore is burnt. The consumption of coke by the furnaces ranges from 1·5 to 3% of the charged ores.

The average analysis of the raw ores and the roasted ores as despatched to the blast-furnace is as follows :

	Fe, %	Mn, %	SiO, %
(*a*) Raw ore	30–33	3·6	13–18
(*b*) Dressed ore	35–38	5·7	7–10
(*c*) Roasted ore	47–50	8–10	7–10

Non-Ferrous Metals

The non-ferrous metals contained in the ores as hand picked, along with the slimes from the dressing plants, are despatched to two central flotation plants, the Altenseelbach and the Victoria Lettfeld Plants, where the products in 1943 were as follows :

Copper	712 tons
Zinc	826 tons
Lead	87·6 tons
Gold	12·58 kg.
Silver	651·7 kg.

Despatch

The mines throughout the Siegerland district are con-

nected by broad-gauge railways to the main lines, and loading is done directly from hoppers into railway waggons. Statistics and particulars of each of the Siegerland mines are shown in Tables VII and VIII.

General

The boundaries of the British and French Zones of Occupation coincide with the boundaries of the Province of Westphalia, which includes the Landkreis Siegon and the Rhineland Province of which the Kreis Altenkirchen forms a part.

The economic interests of the mines tend towards Westphalia, for by far the larger part of their production was treated there. About 70% of the total production was smelted in the Ruhr district and the remaining 30% in the British and French Zones in Siegerland.

It is reported that the transport of goods between the two zones meets with many difficulties. Special permission from the authorities for the transport of goods is necessary, and it is only granted on a barter trade basis.

In this connection it is of interest to note that the winding shaft of the Eisenzecher Zug mine is in the British Zone, whereas the ventilation shaft is in the French Zone. The blast-furnaces of the Charlottenhutte iron and steel works are situated in the British Zone, but all the other departments of these works, such as

TABLE VIII—*Schedule of Iron Ores from the Siegerland District (French Zone)*

Classification of ores : R = Raw Ore, L = Lumps, F = Fines, M = Middles, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946 tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Siegerland	Rohstoff, Vereinigte Stahlwerke, A.G.	Anxloch	30,539	1000	Target 5000	L*	R, 100	30·00	4·80	...	17·5	...	...	...	3255	
						M	L									
						F	F									
							C	31·50	5·00		15·0					
							RO/I									
							RO/II									
		San Fernando	450,000	14,000	Target 10,000	L	R, 100	29·8	5·80	0·48	17·5	1·25	...	...	6006	Crushing, screening, and roasting plant at the mine
						M	L									
						F	F	35·20	7·10	...	5·50					
							C	49·90	9·50	...	9·00					
							RO/I	40·00	7·70	...	19·50				14,990	
							RO/II									
	Krupp	Friedrich	8000	1000	Target 500	L	R	32·00	6·70	0·40	11·00	1·50	0·01	1·40	195	
						M	L									
						F	F									
							C									
							RO/I									
							RO/II									
		Vereinigung	624,000	17,000	Target 10,000	L	R, 100								2335	Crushing, screening, and roasting plant at the mine
						M*	L									
						F	F	32·00	7·00	0·50	11·00	1·20	0·01	1·20		
							C	47–48	11·00	0·50	6–10	1·20	0·01	1·50		
							RO/I	42–44	9·50	0·60	16—18	1·40	0·01	1·60		
							RO/II									
		Fusseberg Wolf	2,400,000	27,000	Target 20,000	L	R, 100	35·00	7·00	0·40	5·50	0·16	0·005	2·40	16,431	
						M*	L									
						F	F	29·00	5·80	0·85	18·30	2·20	0·008	2·60		,,
							C	49·60	9·00	0·95	8·60	0·70	0·004	3·80		
							RO/I	41·30	8·50	0·75	21·40	1·15	0·008	3·30	9661	
							RO/II									
		Georg	800,000	11,000	Target 1000	L	R, 100	29·60	5·65	...	17·90	1·23	...	2·50	2520	
						M*	L									
						F	F	32·40	6·03	0·93	10·80	1·23	0·005			,,
							C									
							RO/I	49·20	9·20	1·10	10·60	0·05	0·005	3·80		
							RO/II	41·20	7·77	1·10	20·70	0·75	0·006	2·85	22,821	
		Eupel	400,000	10,000	Target 1000	L	R, 100	30·89	7·03	...	14·50	0·70	...	5·10		
						M*	L									
						F	F									,,
							C									
							RO/I	48·17	10·91	1·30	7·66	1·70	0·006	5·10	8150	
							RO/II	...	...	...	...	...	...	...		

* Screen sizes

the rolling mill, hammer mill, and mechanical workshops are in the French Zone.

It would therefore appear that if the Province of Altenkirchen cannot be incorporated into the British Zone, some agreement should be made with the French authorities to control the production of ores.

Section IV—Lahn-Dill and Vogelsberg Deposits

Lahn-Dill Deposit

The Lahn-Dill mining district occupies the major part of the Dillkreis, Kreis Wetzler, and Kreis Oberlahn in Hessen, Nassau, in the American Zone. The deposits are situated approximately 50 miles south-east of Siegen.

The ore body belongs to the Devonian and lower carboniferous sediments (sandstones, quartzites ; schists of two syncline troughs with an intervening anticline running south west to north east). These two troughs are called ' mulde ' and thus we have the Lahnmulde and the Dillmulde with a barren stretch of land between them.

The whole of this geological structure has been complicated by volcanic action causing folds and faulting, and intrusions with diabase. The ground pressures in the mines are reported to be heavy, and although repair gangs have been employed since production ceased, the mines will not be in a fit condition to produce the normal output for 6 to 12 months. The present condition of some of the mines, as reported by the management, is such as to cause alarm, and they urge that the mines be reactivated as quickly as possible.

The companies in the Ruhr which normally drew supplies from this district

TABLE IX—*Schedule of Iron Ores from the Lahn-Dill District (American Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening, Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Lahn-Dill	Mannesmann	Krumm	90,000	1000	(Target nil)	L M F	R L F C	45·00	0·12	9·50	8·50	...	0·15	...	R 4000	Mine flooded
		Koenigsberger	10,000	1250	800	L M F	R L F	37·70	0·17	13·60	14·40	3·60	0·36	1·60	R 7500	Underground workings
		Vereinigte Constance	100,000	2500	1000	L M F	R L F	32·00	0·20	10·60	12·90	3·60	0·36	0·80	Nil	Shaft 250 m. deep. Lower level flooded
	Private owner	Arthur	20,000	550	Nil	L M F	R L F	26·60	0·15	13·20	28·90	4·20	0·36	1·80	R 3450	Mine flooded
		Hasserod	15,000	400	300		R	28·00	...	15·00	8·00	...	...	...	R 14,500	Primitive shallow workings
	Buderus	Allerheiligen	200,000	1560	1000	L, 80 M, 25 F, 0	R, red iron Fluxing iron	42·10 27·30	0·30 0·25	22·60 17·34	12·45 11·45	6·70 5·02	0·36 0·17	1·48 3·19	R 6,000	Underground workings 90 m. deep. Crushing and screening plant at the mine
		Georg Joseph	235,000	3120	1000	L, 80 M, 15 F, 1	R, red iron ore	31·88	...	19·84	14·17	...	0·15	0·51	R 4500	Underground workings
		Gute Hoffnung	17,100	300	Nil	...	...	25·00		50·09	6·00	...	...	...	400	Adit mine still in development stage
		Friedberg	375,000	1820	1050	...	R, brown ironstone	30·93	4·27	0·52	20·30	4·34	0·22	0·43	R 12,000	Underground workings 110 m. deep
		August Stollen	450,000	2660	2000	L, 80 M, 25 F	Red ore Fluxing ore	42·70 32·40	0·18 0·14	38·09 18·26	27·25 16·10	4·06 6·47	0·10 0·14	0·20 0·48	R 75,000 —	Adit and open-cast mine
		Koenigszug	340,000	10,920	5000	L, 80 M, 25 F	Red ore Fluxing ore	45·32 54·91	0·12 0·13	3·09 14·07	22·20 16·80	2·37 3·38	0·25 0·16	0·85 0·60	R 24,000 ...	Underground workings 400 m. deep

are Mannesmann, Gutehoffnungshutte, Dortmunder Union, and Deutsche Eisenwerke.

Lead, zinc, some copper, and traces of nickel ores are also found in the area.

Types of Ores

Both the Lahnmulde and the Dillmulde contain several different types of iron ore, and practically all of them are comparatively high in phosphorus. The prevailing type, however, is a hematite of 40–80% of iron, low in lime, and high in silica. The silica content ranges from 18 to 24%, and the phosphorus content from 0·15 to 0·66%. There are also in this area, deposits of self-fluxing iron ores with 32–36% of Fe, 12–19% of CaO, and 11–13% of SiO_2, in which the iron occurs as hematite. Limonite also occurs with 3–4% of Mn. One special type of ore was found at two other mines ; one in each mulde. This ore was used as an ' annealing ' ore. During 1941–42, inclusive, 40,000 tons of this ore were produced by these two mines, the Buchwald and Augusttollen mines, which are owned by the Buderus'sche Eisenwerke and Kluser & Co. The V.S.E. report that Ruhr furnaces require, immediately, 1000 tons/month, and press for reactivation of the mines.

Production

The mines in the Lahn-Dill area are owned and operated by Mannesmann, Vereinigte Stahlwerker, Buderus'sche Eisenwerke, and in a few cases by private owners.

The particulars of the mines, the owners, normal and estimated present output, the stocks, and the analyses of the ores, are shown in Tables IX and X.

The normal production in the district was, as shown above, 411,000 tons/year, and the distribution of the ore was as follows :

	Total Consumption, tons
Buderus'sche Eisenwerke ...	276,000
Annealing ores	40,000
The Ruhr	95,000
	411,000

Despatch of Ores

The ores were loaded from hoppers into main-line railway waggons at the mines, and were despatched by rail to the blast-furnaces in the Ruhr and the Buderus'sche Eisenwerke, as shown above.

Vogelsberg Deposits

The mines in this district in the American Zone, are owned and operated by Buderus'sche Eisenwerke, Krupp, and Gewerkschaft Konstanze, Dusseldorf.

The Vogelsberg ore is a clayey limonite, occurring in shallow troughs in the basalt flow which underlies the whole surface of the district. As mined, the ore is too low a grade for direct smelting and is given a preliminary washing to remove the clay and to clean the small hard pebbles of limonite. Recoveries in the washery plants are low, and only the cheap mining of the ore due to the shallow depth and the soft earthy nature of the ore body makes it economically possible as a source of iron.

As indicated, mining in this district is all open-cast. The overburden measures from 2 to 10 m., and consists of soft alluvial gravel and clay. The depth of the ore body ranges from 5 to 7 m.

The iron content of the washed product is substantially higher than the average German domestic ores. This high yield is achieved, however, at the expense of a very considerable loss of iron in the tailings, for both the gravel and the clay contain a very high percentage of iron. The washed pebbles contain no lime and of from 9 to 10% of silica. The analyses of the ores are shown in Table XI.

One mine in this district, the Fernie mine, owned by Krupp, A.G., deserves special mention. It is not situated on the main Vogelsberg deposit, but on an independent ore body, which appears to extend from the Geier mine on the Rhine in the French Zone, to Giessen in the American Zone. Both the Geier and the Fernie mines operate rich deposits of manganiferous ores ; at the Fernie mine the manganese content is shown as 13·7%, and at the Geier mine it is 18·00%.

The Fernie ore body is a limonite resting on an extremely irregular deposit of Tertiary limestone. In consequence it varies considerably in thickness. It is worked as an open-cast mine in one section and in underground workings in another. At the open-cast section the overburden consists of soft earthy material (clay, sand, and marl), and measures from 8 to 10 m. in thickness. At the underground section the overburden measures approximately 25 m. (82 ft.). In view of the shortage of manganiferous ores it is suggested that this mine be reactivated as soon as possible and that every effort be made to raise the rate of production to the maximum figure.

The particulars of the mines in the Vogelsberg district, the normal and estimated present output, the stocks, and the analyses of the ores are shown in Table XI.

Section V—The Wesergebirge Iron-Ore Deposits

The Wesergebirge deposits are situated in the Weser and South Oldenberg district, and are about 6 miles south of Minden.

They consist of two distinct layers of ironstone, which are known as the ' Klippen Floz ' and the

TABLE X—*Schedule of Iron Ores from the Lahn-Dill District—(American Zone) (Cont.)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middes, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening. Sizes. mm.	Analysis of Ores								Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons		Ore Classification. %	Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Lahn-Dill	Buderus	Laufender	59,600	1000	500	L, < 80 M, < 25 F	Red ore Wasteore	36·74 27·50	0·18 0·20	5·84 3·15	24·56 27·45	6·43 3·17	1·12 0·14	1·22 1·09	R 4100	Underground workings 150 m. deep
		Friederichs Zug	73,400	1800	800	L, ... M, ... F, ...	Red ore Waste ore	36·64 27·74	0·16 0·09	6·45 3·55	26·54 28·05	3·77 6·04	0·17 0·18	19·4 0·58	R 9000	Underground workings 300 m. deep
		Neuhist	77,200	1500	1000		Red ore	34·61	0·10	11·94	17·03	6·66	0·21	0·80	R 450	Underground workings 150 m. deep
		Amalie	107,000	2300	700	L, <30 M, <25 F, 0	Red ore	34·71	0·15	7·63	22·46	6·30	0·18	2·40	R 3400	Open-cast workings, Underground workings 270 m. deep
	Krupp	Mardorf (Vogelsberg)	11,300	3000	1000	...	Brown ore	34·57	0·82	0·71	16·96	1·48	0·05	0·63	R 6000	Underground workings 90 m. deep
		Anna	58,000	2000	1000	...	Fluxing ore	36·00	0·20	16·24	16·80	2·30	0·22	0·60	R 20,000	Underground workings
		Eisensegen	150,000	3000	2000	...	Red iron ore	43·00	0·20	1·00	22·10	5·10	0·30	0·30	R 37,700	,,
		Erhaltung	25,000	1800	1000	...	Red iron ore	42·00	0·30	5·94	20·90	4·30	0·20	1·50	R 37,800	,,
		Fortuna	150,000	3000	1500	...	Red iron ore	36·00	0·15	5·50	23·60	6·10	0·18	1·10	R 5900	,,
		Fritz	5000	2000	1000	...	Brown iron ore	32·00	2·50	1·80	21·90	11·00	0·98	0·40	R 19,000	,,
		Heinrichsegen	150,000	4000	2000	...	Red iron ore	3·06	0·20	5·60	28·90	2·20	0·14	0·30	R 55,000	
		Laubach	100,000	4000	2000	...	Brown iron ore Red iron ore	36·00 38·00	4·00 0·30	1·50 2·20	19·50 32·00	8·30 4·60	0·70 0·20	0·20 0·25	R 23,000	
		Lindenberg	100,000	1000	500	...	Red iron ore	45·40	0·01	...	15·4	...	...	...	R 4700	
		Strichen	40,000	1000	Target 500	...	Magnetic ironstone Kieselguhr and ironstone	42·00 34·00	0·20 0·20	4·00 3·40	21·00 31·20	1·80 17·00	0·15 0·13	0·80 0·70	R 8000	Underground workings Siliceous ores : underground works
		Waldhausen	70,000	1500	700	...	Red ironstone Kieselguhr and ironstone	38·00 36·00	0·20 0·20	1·10 0·70	39·50 35·00	2·00 1·70	0·24 0·17	0·20 0·15	R 7000	Underground workings Siliceous ores
		Zollhaus	150,000	3000	1500	...	Brown ironstone	33·00	3·50	3·00	23·00	6·50	1·40	0·70	R 18,000	Underground workings

TABLE XI—*Schedule of Iron Ores from the Vogelsberg, Württemberg, Donaueschingen, and Bavarian Districts (American Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Analysis of Ores								Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons		Ore Classification, %	Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Vogelsberg	Mannesmann	Vereinigter ... Wilhelm	...	1250	1000	...	Brown ironstone	6·50	0·43	0·65	8·80	8·00	0·40	0·20	1500	Underground workings Ore is washed by primitive methods at the mine
	Buderus	Abendstern	4000	1000	750	...	Brown ironstone	42·70	0·40	..	10·67	8·83	0·31	0·34	25,000 (Washed ore)	Open cast work. Practically exhausted
		Albert	96,000	1500	1000	...	,,	40·27	0·35	...	11·77	12·15	0·42	0·37	6000 (Washed ore)	Underground workings. Ore is washed at the mine (*see* text)
	Vestag	Louise Mücke	500,000	4000	2000	...	,,	38·68	0·52	0·22	8·46	8·20	0·28	0·19	...	Open cast mine, ore washed at the mine
	Krupp	Fernie	2,000,000	10,000	7000	...	Manganiferous ore	18·00	13·00	0·70	23·70	16·30	0·06	0·60	R 11,000	Raw ore dispatched to Ruhr. Underground and open cast-mine. No crushing or screening at the mine
Württemberg	Gutehoffnungshutte	Geislingen (Karl)	4,700,000	75,000	35,000	L, < 80 M, 8–80 F, 8	Dogger ores R F C	 32·21 36·33	 0·47 0·44	 10·50 5·30	 19·40 21·65		 0·33 0·37		R 89,000	Underground workings on the Murchison seam only Crushing, screening, and washing plant at mine. Mechanical and magnetic drying preparation
Donaueschingen	Gutehoffnungshutte	Karl Egon (Gutanadingen)	...	...	...	L, > 70 M, ... F, < 8	R F C	23·60 26·40	0·17 0·16	11·84 13·04	21·60 17·00	... 7·75	0·40 0·47	... 1·86		Macrophalus deposit. Mine closed in 1940. Crushing and screening plant stripped
Württemberg (Dogger)	Gutehoffnungshutte	Faber du Faur	1,100,000	25,000	Target 10,000	...	R	26·40	0·29	5·84	36·43	...	0·25	...	R 1000	Adit mine
Bavaria	Maxhütte	Arzberg	1,500,000	7500	5000	...	Spatic, R	35·50	1·60	3·00	13·00	2·50	0·15	0·60		No ores sent to the Ruhr
		Maffei	6,000,000	25,000	15,000		Brown ore (R) Limonite	48·00 32·50	0·50 1·10	0·30 3·00	18·00 24·00	1·50 3·00	0·50 1·00	0·20 0·80	R 60,000	⅓ Limonite, ⅔ Spatic Ore. Ore transported to Arzberg
		Karoline	...	...	...	...	Brown ore	51·50	0·50	0·40	9·50	3·00	0·65	0·30		Ores transported to Arzberg
(Dogger ore)	Reichswerke	Pegnitz	10,000,000	30,000	15,000	...	R C	26·20 36·00	0·20 0·40	0·30 0·80	29·00 16·00	...	0·30 0·40	...	120,000	Crushing, screening, and magnetic separation plant at mine. Adit mine ; longwall system of mining. Modern plant

'Wittenkind Floz.' Both are oolitically embedded in massive limestone and the ore body can best be described as ferrugenous limestone with an overall average of only 4–6% of iron. The iron-bearing strata, however, vary considerably, some seams containing up to 13–15% of iron, and it is only these which were being mined. The average thickness of the seams ranged from 2 to 7 m. A typical average analysis of the better seams is as follows :

Fe, %	Mn, %	SiO_2, %
12·31	0·09	11·84
P, %	**S, %**	**CaO, %**
0·18	0·00	35·33
MgO, %	**Al_2O_3, %**	
1·80	2·74	

Details of the mines are shown in Table XII.

There are two mines in the 'Klippen Floz,' the Wohlverwahrt and the Nammen, in the Minden district. The Porta mine, also in this district, works the 'Wittenkind Floz' seam.

Wohlverwahrt Mine

The mine workings are approached by an incline shaft dipping at 11° and measuring 1950 m. in length, and the shaft was sunk beneath the ore body. Cross-cuts were driven at each level to meet the seams.

The payable ore measures 6 m. in thickness and is worked in three benches. The stopes are opened out over a length of 80 m., and pillars are left to support the hanging wall. The haulage galleries on each level are driven in the footwall beneath the payable ore, and the broken ore is discharged through shoots and ore boxes into the trucks, each of which

TABLE XII—*Schedule of Ores from the Weserge birge and Osnabrück District (British Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores						Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %	
Weserge birge	Vestag	Nammen	5,000,000	2500	25000	L, 150–100 M, 100–10 F, 10–0	R, 100 M, 89 F, 11	13·40 12·90 16·00	0·10	35·00 35·20 32·30	9·5 10·0 11·1	2·70	0·20	1·60	1478	Moisture : R, 1·6%; M, 2·5%, F, 3·7%; Raw ore despatched to Ruhr. Crushing and screening plant at the mine. Underground workings.
		Wohlverwahrt	10,000,000	13,000	13,500	L, 150–100 M, 100–10 F, 10–0	R, 100 M, 80 F, 20	14·00 13·60 15·75	0·09	32·50 32·20 31·85	11·00 11·40 13·53	2·73	0·20	1·80	998	Moisture content : R, 1·85%, M, 2·0%, F, 3·65%. Crushing and screening plant at the mine. Raw ore despatched to Ruhr. Underground workings
		Porta	2,700,000	45,000	Nil (target 30,000)	L M F	R M F	23·26	0·31	10·26	16·37	7·90	0·51	2·34	199,140	Reactivation of mine expected May, 1946, awaiting completion of railway bridge over Weser. Crushing, screening, and ore-dressingplant at the mine. Underground workings
		Damme	...	...	...	...	...	...	...	...	...	...	...	...		Underground workings. Mines still in development stage
Osnabrück	Klöckner	Fred Wilhelm	800,000				R	28·45	...	...	...	...	0·03	...	Mine abandoned (*see* text)	Crushing, screening, and ore-dressingplant at the mine
		Hugel	Limestone 2,000,000		...	...	R	35·00 8·90	1·80 0·70	12·50 35·00	...	...	...	...		Mine abandoned in 1930, open-cast mine is worked for its limestone which is used as a flux containing 8·9% of Fe.
		Hector and Perm	Nil	...	...	...	...	...	...	...	...	...	...	12·00		Mine abandoned (*see* text)

TABLE XIII—*Results of Analysis of Ore Washings at the Ida Plant*

	Fe, %	Mn, %	SiO_2, %	CaO, %	MgO, %	Al_2O_3, %	P, %	S, %
Raw ore	23·21	0·22	29·04	11·34	1·23	6·9	0·45	0·16
Concentrates I	37·73	0·25	13·22	7·31	1·37	5·42	1·45	0·14
Concentrates II	40·70	0·25	15·22	4·82	1·06	5·02	1·01	0·12

carries 3½ tons of ore. Mining is straightforward, and as the ore is particularly limey and comparatively near the Ruhr it has advantages as a balancing factor in building up the furnace burden. The mined ore is hauled to the surface, crushed to 100-m. size, and screened to 0–5 mm. and 5–100 mm.

Owing to the cut in the electricity supply, pumping was stopped on the cessation of hostilities, and in consequence the lower levels of the mine were flooded. Out of a total length of 1950 m. of the incline shaft 1130 m. were under water. Pumping was resumed in October, 1945, and it is estimated that the mine would not be completely de-watered until the end of January, 1946. In the meantime it is possible to work the upper levels, and assuming that the mine is reactivated at once, it is estimated that 50,000 tons can be hauled per month. The normal output was 100,000 tons per month. The stocks of ores on the surface are only 930 tons. The reserves are large ; definite figures are not at present available. The limestone as worked in the galleries was sold for roadmaking, etc.

Nammen Mine

This is an adit mine with an adit of 8000 m. in length.

Mining was carried out on the same lines as at the Wohlverwahrt mine. The mine is equipped with a modern mechanical installation for the loading and discharge of ore, with a storage capacity of 60,000 tons.

The ores from both mines are transported over the Minden district railway (Mindener Kreisbahn) to the main railway at Minden, and/or to the Minden port on the Mitelland Canal.

Porta Mine

The Porta mine worked an oolitic ironstone of clayey character. The workable thickness of the bed averaged 1·2 m. Where the ' Klippen Floz ' is imbedded in limestone the ' Wittenkind Floz,' though richer in iron, is embedded in a clayey mass. Both layers belong to the group of poor oolitic ores.

Mining is carried out by the longwall system, allowing the roof to cave-in behind the workings. The panels measure 120 m. in length. In places where the roof is bad, the panel is divided into diagonal sections.

The transport of ore underground is mechanized throughout ; air-driven jigger shaker conveyors of the Joy type, and electrically-driven scrapers being in use at the working faces, and mechanical haulage in the main galleries. The upper levels were approached by adits, and in 1938 a shaft was sunk to work the lower levels. In 1940, an in-rush of water flooded this shaft, and all work on the lower levels was stopped.

The reserves of blocked-out ore on the upper levels amount to about 3,300,000 tons, and will suffice for a monthly production of 50,000 tons for a period of 5 years.

At present the ore cannot be despatched to the Ruhr because the railway bridge over the Weser is down.

Damme Mine

This mine is still in the exploration stage. A shaft of 260 m. in depth has been sunk, and a main cross-cut has been driven under the deposit which consists of limonite pebbles and a clayey matrix. The length along the strike measures 1·5 to 6 m., and the dip is approximately 3–5° south. The ore body is overlain by fine-grained sandy and friable marls. Mining will be difficult owing to the bad nature of the roof.

An average analysis of the raw ore is as follows :

Fe, %	CaO, %	SiO_2 %	P, %	Al_2O_3, %
25	14	19	0·55	4·4

Experiments in ore washing were carried out at the Ida Plant on the 8th October, 1945, and the results were as in Table XIII.

In view of the conditions of the mine, the bad roof, and the necessity of transporting the raw ore to outside washery plants, it is not considered advisable at this stage, to continue the development of the mine on a large scale, but on the other hand the workings should be maintained, and two headings driven to open out the seam.

Schafberge and Hüggel Deposits

In the vicinity of Osnabrück there are two small deposits of iron ores, the Schafberge and the Hüggel deposits, particulars of which are given in Table XII.

Schafberge

The ore body is practically exhausted, and the

Hector mine which mined it has been abandoned. One pillar with about 20,000 tons of ore remains, but it lies directly beneath a densely populated area and cannot be recovered. There are no stocks at the mine.

Perm Mine—This mine also worked this deposit, but it, too, has been abandoned. It was an adit mine, and below the adit there is still some slimy ochre in a water-logged strata. According to an old drawing and records, a further 15,000 tons of ochre outcrop remain, but the workings are buried in sand and therefore they are worthless. There are no stocks.

Friedrich Wilhelm Mine—This mine has also been abandoned. There is still a traceable reserve of 800,000 tons, but after all the dead work has been carried out only 120 tons/day could be mined. The average analysis as taken between 1911 and 1921 is as follows :

	Fe, %	P, %	H_2O, %
Raw ore, as mined	28·45	0·032	25·8
Dry ore	38·34	0·43	—

The ore was won partly by underground working and the remainder by open-cast mining.

Hüggel

The underground workings of the Hüggel mine, the only one in this deposit, have been abandoned, but the surface workings, as explained below, are still carrying on. The workings were originally all underground. These were stopped in. 1930.

The overlying Permian limestone deposit is of value, however, and has been estimated at 2,000,000 tons. It is at present being worked as a flux. The iron ore which occurs in this deposit of limestone is worked along with the limestone.

	Daily Output of Lime, tons	Daily Output of Ore, tons
Normal ...	... 150	20
Potential	... 200	25

The analyses are as follows :

	Fe, %	Mn, %	CaO, %	MgO, %	H_2O, %
Ore	35	1·8	12·5	—	16·48
Lime	8·9	0·7	35·0	12·0	8·3

Section VI—Baden, Württemberg, and Bavarian Dogger-Ore Deposits

The dogger ores of Germany are located near Freiburg in Baden, at Geislingen in the Württemberg district, at Pegnitz in Bavaria, and at Zollhaus Blumberg near the Swiss border in the French Zone.

These ores are made up of the following seams :

Ornaten
Macrocephalen
Gigantens
Sowerbyi
Murchison
Opalypus

The Macrocephalen seams contain a high percentage of lime. An average analysis is as follows :

Fe, %	CaO, %	SiO_2, %	P, %	Mn, %
20	25	15	0·3	0·3

It is worked at the Kahlenberg and Schonberg mines near Freiburg, and at the Karl and Faber du Faur mines in Württemberg. The Karl mine also works a portion of the Murchison seam. The Pegnitz mine at Pegnitz works the Murchison seam only.

Baden Dogger Ores

Particulars of the mines, owners, and analyses of the ores in this area are given in Table XIV.

Kahlenberg Mine

This is an open-cast and adit mine belonging to Vereinigte Stahlwerke. It was planned for an output of 3000 tons/day. The ore body dips at 10–18°, and the mine workings are connected to the Reichsbahn by an overhead ropeway 800 m. long, and by a narrow-gauge (600 mm.) railway. The ropeway is capable of handling 130 tons/hr. The balance was transported over the light railway. The normal output was 2000 tons/day. The ore reserves are as follows :

	Output, tons
Open-cast	11,000,000
Adit workings ...	8,000,000
	19,000,000

In the open-cast working 445,000 tons of ore are exposed. Two cubic metres of the overburden are removed to 1 ton of iron ore extracted, and the cost of mining, excluding overhead charges, was 5 reichsmarks/ton of ore.

The ore is crushed and screened to 100-mm. size, and all below 10 mm. was despatched for sintering. The results of crushing were as follows :

Size, mm.	Wt., %
25–100	17
10– 25	10

The ore is not washed : An average analysis of the raw ore is :

Fe, %	CaO, %	Mn, %	SiO_2, %	Al_2O_3, %	MgO, %
20·4	23·7	0·2	17·9	4·43	1·05

Labour—There is apparently no shortage of miners in this area ; the number of surface employees was 34, and miners 400 for an output of 2000 tons/day.

Stores—Consumable stores for an output of 2000 tons/day were as follows :

Consumable Commodity	Amount per Month
Coal and coke	50 tons
Electric power	300,000 kWh.
Diesel oil	2,500 kg.
Timber	100 cu. m.
Explosives...	15,000 kg.
Detonators	50,000
Steel	6 tons

Despatch—The different grades of ore as above

were railed to Kehl or to Mannheim on the Rhine, and from there they were shipped in barges to Duisberg. Many of the Rhine barges are reported to have been sunk during the war and the remainder confiscated by the French authorities. The V.S.E. Ores Panel have been instructed to make enquiries regarding the transportation of ores on the Rhine, and to report on the position as early as possible.

General—The mine managements have reported that the French authorities have ordered that the plant and machinery required for working the 445,000 tons of exposed ore in the open-cast workings at the Kahlenberg mine may remain until the ore has been removed. The remaining plant and machinery, *i.e.* the plant in the adit workings, is to be despatched to France. These ores may be required to balance the acid ores from Salzgitter, and if so, the removal of the plant and machinery may seriously affect the output of iron and steel. A joint investigation at the mine with the French authorities may therefore be advisable.

Schönberg Mine

This mine also belongs to the Vereinigte Stahlwerke, and is in two parts; the St. Georgin and the Ebringen sections, which are situated approximately 2 miles south of Freiburg. Both sections are underground workings approached by adits. The thickness of the seams is from 6 to 7 m., dipping at 25–30°. The reserves are as follows :

Reserve	Estimated Capacity, tons
Visible	2,000,000
Probable	10,000,000
Possible	58,000,000

Production—The maximum output from this mine was 2000 tons/day, but under present conditions it would be unwise to calculate on more than 500 tons/day after a period of 3 months, during which time the initial repairs necessary for production should have been completed. Underground transport is done by jig shakers of the Joy type, and conveyor belts.

An average analysis of the raw ore is as follows :

Fe, %	CaO, %	SiO_2, %
20	14·7	33

Despatch—The raw ore, as mined, was crushed and screened as at the Kahlenberg mine and loaded directly into waggons which were railed to Kehl and Mannheim for despatch by barges to the Ruhr.

TABLE XIV—*Schedule of Iron Ores from the Taunus and Baden Districts (French Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores							Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %		
Taunus	Gewerkschaft Dr. Geler (Mannesmann)	Dr. Geler	1,500,000	13,250	Target 10,000	L M. F	R, 100 L F C RO/I RO/II	28·44	17·61	0·28	10·92	7·38	0·20	0·62	Raw ore 35,000	24% of moisture in R. Crushing, screening, and roasting plant at the mine Underground workings
Baden (Dogger ores)	Vestag	Kahlenberg	19,000,000	50,000	Target 35,000	L, 100–10 M, 25–10 F	R L F C	18·13 20·85	0·16	26·32 23·73	14·72 17·04	3·45 ...	0·31 ...	0·87 ...		7% of moisture in R. Crushing and screening plant at the mine. Open-cast and underground
		Schönberg	2,000,000	25,000	Target Nil	L M F	R L F C	19·19 19·68 20·93 ...	0·12	15·94 16·20 14·77 ...	16·89 22·25 23·06 ...	5·06	0·30	1·62		9% of moisture in R. Mine at present closed and partly stripped
	G. H. H.	Karl Egon (Gutmadingen)	13,000,000	10,000		L M F	R, 100 L F C									
	Doggererzges	Zollhaus Blumberg	400,000,000	76,500	Nil (target nil)	L M F C	R L F C (largt) C (slmt.)	19·45 26·65 38·71 42·00	0·17 0·15 0·13 0·20 ...	12·98 11·83 9·51 8·50 ...	22·06 22·42 17·72 17·00 ...	11·49 11·21 11·82 7·00 ...	0·44 0·43 0·51 0·70 ...	2·59 1·63 2·97		11% of moisture in R. (For particulars of mine and plant *see* text)

Württemburg Dogger Ores

Particulars of these ores are given in Table XI.

Karl Mine

The ore at this mine is semi-oolitic and the normal output was 3000 tons/day, or 75,000 tons/month. The mine is owned by Gutehoffnungshütte, and the reserves are as follows :

Reserve	Estimated Capacity, tons
Visible	915,000
Probable	1,700,000
Possible	12,800,000

The ore body dips at 2–3°, and the longwall system of mining is used throughout, leaving 30-ft. pillars at the shafts and main galleries. The roof is controlled by chocks built of old rails.

The unwashed ore is crushed and screened with the following results :

Fines	0–8 mm.
Coarse	8–80 mm.
Lump	80–100 mm.

An average analysis of the ores was as follows :

	FeO, %	CaO, %	Mn, %	SiO_2, %	P, %
Coarse	31·2	5·75	0·53	26·22	0·40
Fines	32·62	5·56	0·52	25·07	0·40

Given the necessary labour, the mine could operate three panels at once, with a total output of 1500 tons per day of 3 shifts.

Labour—Miners are reported to be scarce, for so many of them have been sent to the Ruhr and others have been returned to the Saar. At present there are only 100 miners available.

Stores—The stores consumed for an output of 1500 tons/month were reported to be as follows :

Consumable Commodity	Amount
Electric power	4500 kWh/day
Coal and coke	120 tons/month
Timber	400 cu.m. ,,
Diesel oil	400 kg. ,,
Carbide	1700 kg. ,,
Steel	50–60 tons ,,

Faber du Faur Mine

This mine is owned by Gutehoffnungshütte, A.G., and the reserves are estimated at :

Reserve	Capacity, tons
Visible	100,000
Probable	1,100,000
Possible	2,400,000

The normal output was 1000 tons/day, or 25,000 tons/month, but under present conditions the output would, it is estimated, be not more than 15,000 tons/month for the next six months.

An average analysis of the ores as mined was :

	Fe, %	Mn, %	CaO, %	SiO_2, %	P, %
Coarse	29·77	0·34	3·81	32·42	0·29
Fines	28·69	0·30	2·00	35·66	0·26

Costs—The costs of mining at both mines ranged from 7 to 9 reichsmarks per ton of ore (f.o.r.).

Stores—The consumption of stores was as shown for the Karl mine.

Despatch—The transport of the ores from the Karl and Faber du Faur mines was direct by rail, or by rail to Mannheim or Heilbronn on the Rhine, and then on by barge. Special railway rates were granted by the Government for the despatch of these ores. Loading was done directly from the screens and bunkers into railway waggons.

Pegnitz Dogger Ores

The Pegnitz mine, owned by the Reichswerke, is the only one operating the dogger ore in this area. It is an adit mine, and works the Murchison seam which measures from 1·5 to 2·5 m. in thickness and dips at approximately 5°. The length of the main gallery is 1500 m., which extends to the limit of the ore body.

The ore is mined on the panel longwall system, each panel measuring 80 m. in width. The crosscut galleries off the main gallery are driven out to the boundary ; the working faces retreating towards the main gallery.

The roof is allowed to fall behind the faces. Steel pit props are used throughout the mine. The roof consists of sandstone and clay measuring approximately 3·5 cm., above which is a conglomerate of sandstone pebbles, 30 cm. thick, followed by a fairly strong bed of limestone. The floor consists of a layer, 25 cm. thick, of sandstone under which is a bed of clay. The latter swells out when wet, and constantly pushes the floor upwards. Special precautions are taken to meet this difficulty and the results appear to be satisfactory without being costly.

The chemical composition of different sections of the ore body show certain variations as detailed in the analysis of the five samples given in Table XV. They are, as will be seen, uniformly high in silica and low in lime.

TABLE XV—*Dry Analyses of Pegnitz Ore*

Sample	Fe, %	SiO_2, %	Al_2O_3, %	MgO, %	CaO, %	Mn, %	P, %	S, %	Si, %	Loss
1	26·5	46·5	5·6	0·9	0·3	0·2	0·24	0·000	0·35	7·9
2	31·3	35·8	6·6	1·15	0·55	0·3	0·31	0·007	0·62	10·8
3	32·8	31·0	6·6	1·2	0·8	0·4	0·37	0·000	0·70	0·2
4	31·3	27·2	8·2	0·75	0·3	0·2	0·44	0·013	0·53	10·1
5	35·7	29·3	6·6	0·9	0·55	0·2	0·37	0·000	0·69	8·6

Production—The mine was planned for an output of 2000 tons/day or 50,000 tons/month, and this figure was reached in 1940 but dropped again in 1941. The output figures were as follows :

Year	Output, tons/month
1937	27,400
1938	39,000
1939	48,700
1940	56,900
1941	48,700
1942	36,700
1943	41,700
1944	33,500

The possible output at present is estimated at 20,000 tons/month (*see* Table XI for further particulars).

Labour—The number of miners employed in 1937 was 301, with 264 surface workers ; in 1940 there were 451 miners and 357 surface workers, and in 1944, 300 miners and 264 surface workers. The output per man per shift ranged from 4 to 5 tons. At the working faces the maximum output was 19 tons and the average ranged from 12 to 13 tons per man per shift.

Costs—The costs of mining per ton of ore, in 1944, were as follows :

Item	Cost, reichsmarks
Fuel	0·60
Electric power	0·18
Wages	1·91
Insurance	0·40
Houses	0·07
Materials	0·12
Timber	0·45
Repairs	0·44
Miscellaneous	0·06
Works office	0·35
Main office	0·20
	4·78/ton of ore mined. (In 1941 their costs were 4·0 per ton)
Interest	0·64
Taxes	0·25
Storage of ore	0·44
Taxes on stocks	0·01
Total	6·12 per ton of ore mined
Profit	0·30

Ore Preparation—The ore-preparation plant was erected in 1937 and completed in 1939 at a cost of 5,000,000 reichsmarks.

The ore was crushed in jaw crushers and hammer mills to a size of 35 mm., and passed through drying drums. It was then milled to a size of 0·6 mm. and wind swept for drying before being passed to the magnetic separation plant. The ore was not sintered at the mine, but was despatched in a dry powder form to the Ruhr. It is reported that the losses in transport when loaded into open waggons were considerable.

Stores—For an output of 33,500 tons/month the consumption of stores was as follows :

Consumable Commodity	Amount per Month
Electric power	1300 kWh.
Brown coal	1000–1500 tons
Coke	50 tons
Timber	250 cu. m.
Diesel oil	3500 kg.
Carbide	2½ tons

No explosives were used—the ore was mined by pneumatic picks.

Bavarian Iron Ores

Excluding the Pegnitz dogger ores already described, the Bavarian iron ores are situated in the neighbourhood of Amberg and Zulzbach. These are the richest iron ores in Germany ; their iron content ranging from 45 to 51%, as shown in Table XI.

The Erzberg mine, owned by the Luitpoldhütte, works the deposit at Amberg, and the Maximilianhütte, A.G., operated the Caroline, the Maffei, and Mitzelbuch mines near Zulzbach.

Erzberg Mine

The workings are all underground, and at an average depth of approximately 130 m. The ore is of a brown ironstone, placed in irregularly shaped pockets. The thickness of the ore bodies varies from 1 to 40 m., the average being about 15 m. A deposit of phosphates (Ca_3PO_4) was discovered in one of the pockets, and a shaft was sunk to produce 1000 tons/month. Both the hanging and foot walls contain quicksand which adds considerably to the difficulties and costs of mining. The mine is reported to be in a very bad condition, and the normal rate of production will not be reached for another 6 months. The reserves of visible ores are estimated at 1,500,000 tons, and the stocks on hand, at 60,000 tons.

Production—The normal rate of production was 7500 tons/month but owing to the present condition of the mine it would be unwise to estimate on an output of more than say 5000 tons/month for the next 6 months at least. The cost of mining was 12 reichsmarks per ton of ore.

TABLE XVI—*Analysis of Dogger Ores from the Zollhaus Blumberg Mine*

Ore	Fe, %	Mn, %	SiO_2, %	P, %	S, %	CaO, %	MgO, %	Al_2O_3, %	Moisture, %
Raw ore	19·45	0·17	22·06	0·44	—	12·98	2·6	11·5	11·00
Roasted ore (coarse)	23·90	0·17	24·38	0·48	0·20	16·21	2·74	11·72	0·5
,, ,, (fine)	28·65	0·15	22·42	0·43	0·35	11·83	1·65	11·21	—
Concentrates	38·71	0·13	17·77	0·51	0·07	9·51	2·37	11·82	—

Analysis of Ore—An average analysis of the raw ore is as follows :

Fe,%	CaO, %	Mn, %	SiO_2, %	P,%	Al_2O_3, %
45	0·4	0·3	18·00	0·8	3·0

S, %	MgO, %	Ti, %	Loss
0·1	0·5	0·1	9·4

Labour—The underground workers number 200, and those at the surface, 50. There is apparently no shortage of mine workers.

Stores—For an output of 7500 tons of raw ore per month, the following consumable stores would be required :

Consumable Commodity	Amount
Electric power ...	4700 kWh./day
Timber	250 cu.m./month
Steel	50 tons ,,
Carbide	1250 kg. ,,
Explosives	250 kg. ,,
Diesel oil	850 kg. ,,
Petrol...	100 kg. ,,
Lubricating oil ...	200 kg. ,,

Ore Preparation—The raw ore is crushed and screened at the mine to a size of 100 mm., and all below 20 mm. is despatched to the Dwight–Lloyd sintering plant. Sizes above 20 mm., were despatched directly to the company's blast-furnaces. No ore was sent to the Ruhr.

General—The company produced only foundry iron and cast-iron pipes.

Zulbach Ores

These ores were worked at three mines, the Caroline, the Maffei and Mitzelbach, and the Erzemannsberg which is now worked out. All three are connected underground, and all the ore was hauled up the Caroline shaft.

The Maffei is at Anebach, a distance of 25 km. from the Caroline.

The ore as mined, consists of a brown ironstone limonite with large deposits of spathic ores; actually two thirds of the ore mined is spathic. The dry analysis of these two ores is as follows :

	Fe,%,	Mn, %	CaO, %	SiO_2, %	P,%	Moisture %
Spathic Ores	31–32	1	3·4	18	0·6	15
Limonite Ores	48	0·4	0·3	14	0·5	11–12

Pockets of manganese ore were found, but in such small quantities that it was not profitable to mine them.

Production—The normal output from the Caroline and Maffei mines was 25,000 tons per month, but it is doubtful whether this figure could be reached within one year from reactivation. It should be safe, however, to estimate on from 10,000 to 15,000 tons per month, *i.e.*, of both limonite and spathic ores, within the next 3–4 months.

The Leenie mine was, at the end of hostilities, still in the exploration stage. Some ore may shortly be available from this mine. More details of production are shown in Table XI.

Reserves—The visible ore was reported to be approximately 5,000,000 tons.

Stocks—Very small.

Despatch—The ores were despatched to the company's blast-furnaces at Zulbach. None were sent to the Ruhr.

Stores—The consumption of stores was as follows :

Consumable Commodity	Amount per Year
Electric power	3,000,000 kWh.
Coal	300 ton
Petrol...	600 litres
Diesel oil	1000 litres
Timber	7000 cu. m.
Explosives	25,000 kg.
Carbide	3000 kg.
Steel	150 tons
Rubber hose...	150 m. (400 m. in stock)

Labour—450 miners and surface workers were employed, and these men are said to be available at present.

Zollhaus Blumberg Mine (French Zone)

This mine is owned by the Doggerez Bergbau. G. m. b.H., a company which was formed by the ironworks concerns of the Saar for the purpose of opening and developing the dogger ores in South Baden. The shares were taken up by the five companies as follows :

Rochling	27%
Neunkirchen	27%
Burbach	27%
Dillingen	12½%
Halberger	6½%

The ore body outcrops on a hillside, and although considerable quantities were mined in the surface workings, the great bulk of the ore was to be mined from underground workings. The average thickness of the bed is about 4 m., with a maximum thickness of 10 m. The deposits represents by far the largest quantity of Dogger ores so far opened out. There are four ore-bearing hills, Eichberg, Stoberg, Buchberg, and Ristelberg, with the Aitrach Valley between them. The town of Blumberg is situated at one end of the valley.

Reserves—The reserves have been estimated at 400,000,000 tons.

Mining—The underground ore was won by the pillar and stall system ; undercutting and blowing down the top section. The roof was then allowed to cave in behind the work. This system was later abandoned in favour of blasting from the solid and bringing away the whole face in one round shot, the roof caving as before. The initial development of the underground workings was handicapped by large in-rushes of water, but this difficulty was overcome by cutting sumps and installing large pumps.

A bridge 1·2 km. in length, spanning the

Aitrach Valley, was constructed to transport the ore directly from the adit portal to the crushing and ore-dressing plant.

Output—The output from this mine from 1937 to May, 1942, when it closed down, was as follows :

Year	Output, tons
1937	169,761
1938	444,811
1939	919,730
1940	954,117
1941	918,158
1942	78,519

Further details are shown in Table XVI.

Labour—The number of employees in 1939 was 1460, and in 1941, 1213. The increase in the output per man per shift was accounted for by the opening of the open-cast workings in 1939.

At present the mine and much of the surface plant has been stripped ; the underground cars, locos, tracks, rock-drilling machines, and pumps, etc., were despatched to mines in Upper Silesia. The crushing and dressing plant was sent to the manganese mines in Russia which were then being operated by the Germans.

Ore Dressing—Four roasting furnaces of the Rochling type and one Lurgi rotary kiln were erected for calcining the ore. The analysis of the raw ore was, on an average, as follows :

Fe, %	Mn, %	SiO_2, %	P, %	CaO, %
19·45	0·17	22·06	0·44	12·98

MgO, %	Al_2O_3, %	Moisture, %
2·6	11·5	11·0

The high silica content and the low content of lime, as well as the physical properties of the ore, were not favourable to treatment. If the moisture content increased above a certain limit, the ore, owing to its high alumina content, became soft and sticky. The open-cast ore is fine-grained, and when dry it crumbled and became dusty. For this reason only dry magnetic separation was possible.

The raw ore was crushed to 0–20 mm., and was then subjected to reducing roasting in the rotary kiln. The roasted ore was crushed again to 2 mm., and subsequently separated into high-grade iron concentrates, and waste of a low iron content.

The analysis of the raw ore, the roasted ore, and the concentrates was as shown in Table XVI.

The ore-dressing plant was erected and developed by co-operation with the Lurgi Chemie at Frankfurt, and the Westfalia Dinnendahl Groppel, A.G., Bochum. In 1938 it was first put into operation, and the system was modified in the summer of that year. In November of the same year it was again put into operation.

The rotary kiln is 44 m. long and the outside diameter is 3·10 m. It is heated by coke breeze with a minimum calorific value of 1100–1150 C.H.U./lb. The ore was preheated in the first zone, and roasted at 850–900° C.

The magnetic separation consists of a 9-in. Starkfeld Walzenmagnetscheider of 600 mm. dia. and 1600 mm. working width. In 24 hr. 328 tons of concentrates have been won from 826 tons of raw ore, *i.e.*, approximately 40%.

The concentrates are of a fine ore, non-susceptible to moisture and consisting of 90% of fine-grained material of size less than 1 mm., and 10% above 1 mm., which has to be sintered before being smelted. The capacity of the rotary kiln was 900 tons/24 hr. When work ceased, the dressing plant was to a large extent dismantled. The Lurgi plant, however, remained, and was taken over by the Otavi Copper Corporation with a view to treating the ores for the extraction of vanadium. Apparently little or no work was done and the plant is now standing idle. The plant has been partially stripped, and before any substantial results could be obtained a large amount of capital would have to be found, and at least 9 to 12 months would be spent in putting the new plant into operation.

Further analyses of the ores as given on 28th March, when the author visited the mine, are in Table XVII.

Section VII—Sauerland Deposits

The Sauerland deposits consist of hematite, and to a small extent, of siderite ores. The hematite ore as mined at the Christiane and the Grottenberg mines is a self-fluxing ore, whereas the siderite deposit at the Christianeglück mine is

Table XVII—*Detailed Analyses of Processed Ores from the Blumberg Mine*

	Fe, %	CaO, %	SiO_2, %	CaO : SiO_2, %	Al_2O_3, %	MgO, %	Mn, %	P, %	S, %	Alkalies, %	CO_2, %	Combined Water, %	Moisture, %
Underground	19·50	12·60	20·70	0·61	7·80	1·70	0·19	0·45	0·25	1·50	9·90	7·20	10·00
Open-cast	19·00	11·10	18·90	0·60	7·40	1·30	0·12	0·38	0·06	1·00	9·30	7·10	17·00
Sintering	28·0–31·0	17·6–16·5	29·0–27·0	0·61	...	...	...	...	0·15	...	...	...	...
Fines	29·00	15·40	25·00	0·61	9·50	2·00	0·23	0·52	0·27	1·00	5·00		1·00
Lumps	24·50	15·80	26·00	0·61	9·80	2·20	0·21	0·52	0·25	1·50	7·00		1·00
Concentrates	42·00	8·50	17·00	0·50	7·90	1·90	0·16	0·69	0·20	1·00	...	2·40	...
Tailings	9·15	24·10	34·50	...	10·84	2·90	0·22	1·08	0·42	...	...	12·10	

high in silica and low in lime but has 2% of Mn and 1·56% of P.

The Christiane mine, near Adorf in Kreis Korbach, and the Hasserod mine near Dexbach, Kreis Biedenkopf, belong to Mannesmann. The Christianeglück is a mine privately owned by a Dutch company.

Christiane Mine

This is an underground mine with two shafts. It is connected to the Reichsbahn by a spur line 11 km. in length, with loading bins at Bredelar in Kreis Brilon. The normal output was 5000 tons/month with a force of 183 men. The visible ore reserves are reported to be 1,000,000 tons. There are 11,000 tons of ore in stock on the surface. An average analysis of the ore is :

Fe, %	Mn, %	CaO, %	SiO_2, %
25·3	0·43	18·42	17·89
	P, %	Al_2O_3, %	MgO, %
	0·11	1·78	4·54

Grottenberg Mine

This is an underground working with a normal output of 1000 tons/month. The mine is connected by rail to a loading point at Ludwigshütte, whence the ore was railed to the Ruhr. The reserves of visible ore are estimated at 15,000 tons, with 14,700 tons in stock on the surface.

The average analysis of the ore is :

Fe, %	Mn, %	CaO, %	SiO_2, %	P, %
24·5	0·2	25·0	7·5	0·21

Christianeglück Mine

The normal output of this mine was 2000 tons/month, and after a period of 2–3 months the mine should be able to produce from 1000 to 2000 tons/month. The mine is connected to the Reichsbahn by an overhead ropeway with a capacity of 10 tons/hr. The loading-bin capacity at the Reichsbahn is, however, only 50 tons, which means that a train-load of trucks may be held up for considerable periods during loading operations. The ore was normally despatched to Klockner Werke and Dortmund Horder Hütten Vereinwerke, Dortmund.

An average analysis of the raw ore is :

Fe, %	Mn, %	CaO, %	SiO_2, %	P, %
28·57	2·02	5·67	23·37	1·56

The special attraction of this ore is the manganese and phosphorus content. The stocks of ore on the surface are given as 30,000 tons.

It has been reported that there are manganiferous ore occurrences in thin masses in this area and particularly in the neighbourhood of Hallenberg, but no details are at present available. Messrs. Sachtleben, A.G., are reported to have carried out research work in this connection and they have been asked to report.

Section VIII—Thuringia Iron-Ore Deposits (Russian Zone)

The deposits of iron ores in Thuringia in the Russian Zone, although not large, cover a wide area. They are situated in the neighbourhood of Schmalkalden, Suhl, Schmiedefeld, Kamsdorf, and Lehesten.

As it has not been possible to visit the mines, the following information has been collected from reports by different authorities.

Origin

The formation of the Thuringia deposit is estimated to have taken place during the Tertiary Period, by the tearing open of the territory in which two main and almost parallel faults form the boundaries of the deposit. Small faults opened passages for the circulation of iron-bearing solutions.

The north-western area consists mainly of granites and porphyrites. The south-eastern part is a table-land built up mainly by schist and slates, quartzite, and limestone. The deep ore horizon has its main development near Schmiedefeld, and is characterized by red iron ore beds. This deposit is found only at Schmiedefeld. At all the other places the deposits consist of chamosite, silerite, and magnetite. The red iron ores are entirely absent in the upper horizons. They are represented by seams which vary in thickness between 0·3 to 2·80 m.

Chamosite Ores

These are of a water-bearing silicate of iron and of alumina. In 1940 an average analysis of chamosite was as given in Table XVIII

Reserves

The reserves of chamosite ores as estimated in 1910, were 50,000,000 tons. An investigation in 1929 for the whole of the Thuringia district, however, showed only 6,000,000 tons of first-grade ores and about 4,000,000 tons of second grade.

Table XVIII—*Average Analyses of Chamosite Mined in Thuringia in 1940*

	Fe, %	Mn, %	SiO_2, %	P, %	S, %	CaO, %	MgO, %	Al_2O_3, %	H_2O, %	Loss, %
Raw ore	33	0·45	18·0	0·6	0·3	2·5	2·0	10·0	4·5	17·5
Roasted ore	39·5	0·5	20·0	0·8	0·4	3·0	2·0	11·5	1·2	3·5

Siderite Deposits

These deposits are situated in the neighbourhood of Lehesten and are in the form of what are called Kieskaller (calf pyrites) concretions, of ellipsoidal form, the diameter of which varies between 0·1 and 2·0 m. These concretions consist of dense spherosiderite surrounded by sharply formed cubes of pyrites.

The composition of the ores, as disclosed by analyses of roasted ore, was as follows :

Fe, %	Mn, %	CaO, %	MgO, %	SiO_2, %	Al_2O_3, %	P, %
42	8	2	2	7	1	0·3

The analysis of a sample of raw ore was given as :

Fe, %	Mn, %	P, %	Volatile Matter, %
31·7	6·52	0·26	35·87

Kamsdorf Deposits

Siderite spathic iron ores containing 32–42% of Fe, 3–5% of Mn, and a little phosphorus, are found along with brown iron ores in the Kamsdorf district. An analysis of the siderite ore was as follows :

$FeCO_3$, %	Fe_2O_3, %	$MnCO_3$, %	MnO_2, %	$CaCO_3$, %	CaO,%
75·38	48·64	7·51	3·81	8·36	4·19

$MgCO_3$, %	MgO,%	SiO_2,%	Al_2O_3, %	P, %	$BaSO_4$, %
3·88	0·99	4·15	0·12	0·04	0·50

Output

The output of the Kamsdorf district, which presumably includes brown iron ore containing up to 4·77% of MnO_2 and 1·20% of $BaSO_4$ was as in Table XIX.

These deposits were owned by the Maximilianhütte, and the ores were smelted in furnaces at Unterwellenton.

Klinge Mine

Here the siderite vein situated in gneis is coarse, sparry, and light in colour. It is also associated with brown iron ore and contains one fifth more manganese than the brown iron ore, but the bulk of the deposit is brown iron ore. The mine belongs to the Mommel Company of Schmalkalden. It is an adit mine. In 1944, a shaft was commenced to tap the seam 40 m. below the adit level. In the old open-cast workings the vein measured 30 m. in thickness, which included several ribs of barytes 1–2 m. thick. In the adit workings the vein measures 4–5 m., and at 70 m. below the adit, 2·5 m. thick.

TABLE XIX—*Output from the Kamsdorf Deposits*

Year	Raw Ore, tons	Fe Content, tons	Workers
1939	160,313	12,359	105
1940	169,263	12,965	110
1941	174,867	10,348	110
1942	226,917	12,942	145
1943	207,766	11,351	120
1944	135,281	6175	120 (up to Aug. 31st.)

TABLE XX—*Details of the Output from the Klinge Mine*

Year	Raw Ore, tons	Fe Content, tons	Mn Content, tons	Workers
1939	35,488	12,383	1508	85
1940	37,583	13,709	1667	95
1941	39,049	14,189	1765	95
1942	38,113	13,160	1660	90
1943	32,637	11,754	1357	80
1944	30,431	10,154	1184	90

Reserves—The reserves at this mine are estimated at 1,200,000 tons. The mine is worked on an overhead stoping system, with an output of 1·2 tons per man per shift, *i.e.*, including all underground and surface workers.

Transport—The ore is transported 3000 m. by an aerial ropeway with a capacity of 10–12 tons/hr., to the Mommel mine, and from there it is transported (9 km.) by narrow-gauge railway, to the main line.

Output

For details of output *see* Table XX.

Samples of the ore showed the following analysis:

	Fe, %	Mn, %	P, %	Al_2O_3,%	CaO, %
Siderite	37·9	5·1	—	—	0·4
Brown iron ore	37·4	4·1	0·009	2·00	0·7

	MgO, %	SiO_2, %	Residue, %
Siderite	3·4	—	9·6
Brown iron ore	1·3	—	27·6

Arminius Ore Body

Adjoining the Mommel claims is the Arminius mine which belongs to Krupp.

The average thickness of the brown iron ore is about 2 m. It is strongly mixed with barytes which is hand-picked in the mine. There is no ore-dressing plant at the mine, and apparently no complaints were received from the smelting works.

Output

For details of output *see* Table XXI.

Stahlberg Mine

This mine is in the same area and works an ore body which, like the Mommel mine, is mainly

TABLE XXI—*Details of Output from the Arminius Mine*

Year	Raw Ore, tons	Fe Content, tons	Mn Content, tons	Workers
1939	16,664	5667	69,695	60
1940	26,353	7227	879	75
1941	23,747	6361	700	75
1942	19,704	5256	?	65
1943	25,458	6789	817	90
1944	28,317	7552	908	95

TABLE XXII—*Details of Output from the Stahlberg Mine*

Year	Raw Ore, tons	Fe Content, tons	Mn Content, tons	Workers
1939	36,395	13,077	1892	100
1940	34,577	12,456	1803	99
1941	32,388	12,188	1674	90
1942	25,059	8720	1056	80
1943	26,354	9690	1365	82
1944	26,584	9610	1321	83

brown iron ore associated with small deposits of siderite.

The analyses of samples was as follows :

	Fe, %	Mn, %	CaO, %	MgO, %	Al_2O_3 and SiO_2, %
Siderite	39·30	5·20	1·10	1·50	4·40

	Fe, %	Mn, %	P, %	CuO, %	MgO, %	Al_2O_3, %
Brown iron ore	38·10	5·54	0·01	3·00	1·50	2·50

The Stahlberg ores are not dressed at the mine, but are smelted at the Schmalkalden furnaces to a high manganiferous charcoal pig iron, almost free of sulphur and phosphorus.

Reserves—The visible reserves were estimated at 300,000 tons, with a probable reserve of 1,000,000 to 1,500,000 tons.

Output

For details of output *see* Table XXII.

The Thuringia iron-ore deposits are situated at such a distance from the Ruhr and the Silesian iron and steel works, that it was not practical to despatch ores to either of these centres. Further details of the mines are given in Table XXIII. Normally the output from the mines was consumed by the local smelting works. During the war, however, in 1943, 21,210 tons of iron and 1745 tons of manganese ore were despatched to the Ruhr; 77,544 tons of iron and 2728 tons of manganese to central Germany, and 6493 tons of iron and 133 tons of manganese to Czechoslavakia.

SECTION IX—SUMMARY

The bulk of the iron ores of Germany are clearly acid ores, and the main centre of supply is in the Salzgitter deposits, where large quantities can be mined at reasonably low costs. The basic ores are found in the Harzvorland, which extend from the Goslar area to Blankenburg, just across the Russian border, where there are three large modern mines ; the Am Buchenberg (owned by Mannesman), the Braunesumpf (owned by Krupp, A.G.), and the Drei Kronen mine (owned by Mittelstahlwerke). The only large and modern mine working these deposits in the British Zone is the Echte mine (owned by Krupp, A.G.), and as the supply of basic ores, as a balancing factor, is very limited, every effort should be made to either incorporate the Blankenburg area into the British Zone, or alternatively, to arrange to reactivate the three mines in question, to supply ores to the British Zone. Other deposits of basic ores in Germany are

TABLE—XXIII—*Schedule of Iron Ores from the Harz and Thuringia Districts (Russian Zone)*

Classification of ores : R = Raw Ore, L = Lumps, M = Middles, F = Fines, C = Concentrates, RO = Roasted Ore

District	Mine Owners	Mine	Visible Reserves, tons	Output/Month		Crushing and Screening Sizes, mm.	Ore Classification, %	Analysis of Ores						Stocks in March, 1946, tons	Remarks
				Normal, tons	Present, tons			Fe, %	Mn, %	CaO, %	SiO_2, %	Al_2O_3, %	P, %	MgO, %	
Harz	Mannesmann	Am Buchenberg	10,000,000	20,000	Target 10,000	..	...	30·00	0·20	20·00	1·40	...	0·15	...	Crushing and screening plant at the mine. Modern equipment throughout
	Krupp	Braunesumpf	?	?	?	...	...	31·50	0·50	11·00	21·00	...	0·22	...	? ,,
	Mittelstahl	Drei Kronen	?	?	?	...	Brown ore Manganiferous ore	41·64	2·30	1·13	15·38	...	0·20	...	? ,,
								28·90	17·40	4·97	2·97	...	0·24	...	?
Thuringia	Mommel	Klinge	1,200,000	3000	...	...	Siderite	37·90	5·10	0·40	...	...	...	3·40	(*See text*)
							Brown ore	37·40	4·10	0·70	...	2·00	0·009	1·30	...
	Krupp	Arminius	...	18,664	...	..	Brown Iron ore								No ore-dressing plant at mine (*see* text)
		Stahlberg	300,000 (Probable 1,500,000)	36,395	...	...	Brown Iron ore Siderite	38·10	5·54	3·00	...	2·5	0·01	1·50	... Crushing, screening, and dressing plant at mine
								39·30	5·20	1·10	4·4			1·50	...

in parts of the Lahn-Dill deposits (American Zone) and the Baden dogger ores (French Zone). The Wesergebirge deposits are of a limestone iron ore, and they too will be required for the same purpose. The total output of each Zone, and the total quantities of acid ores as against basic ores available at present in the British, American, and French Zones, excluding the Siegerland iron ores, are as follows :

British Zone

	Estimated Output during 1946, tons/month
Acid ores	360,000
Calcarious ores	73,000
Neutral ores...	7000
Limey ores	50,000
Manganiferous ores ...	
(+ 5% of Mn)	37,000
Total	590,500

French Zone

	Estimated Output during 1946, tons/month
Dogger ores	35,000
Manganiferous ores ...	
(+5% of Mn.)	53,000
Total	88,000

American Zone

	Target, tons/month
Acid ores	62,500
Neutral ores	2300
Manganiferous ores ...	
(+5% of Mn)	7000
Hematite ores	19,900
Total	91,700

	Total Amount, tons/month
Acid ores	471,000
Basic ores	164,000

TABLE XXIV—*Monthly Consumption of Mine Stores for the Present Output in the British Zone*

Mines	Commodity										
	Timber, cu. m.	Coal tons	Explosive, kg.	Carbide, kg.	Lubricants, kg.	Oil + Grease, litres	Diesel Oil, kg.	Cement, tons	Drill Steel, tons	Bricks, tons	Electric Power, Kwh.
Ilseder Hütte	470	180	20,000	8000	2800		1500	60	80		1,410,000
Reichswerke	2514	1110	54,500	11,400	6700		17,000	40	120		3,400,000
Kruppsche Bergverwaltung	330	25	5000	2500	1400		1200	6	6		300,000
Rohstoffbetriebe	310	200	6750	2450	1400		1250	16	23		520,000
Niedersächs, Eisenerzbergbau	3624	1515	86,250	24,350	12,300		20,950	122	229		5,630,000
Steinberg Mannesmann-Werke		1	600		35	8	2500				2000
Marie Caroline Mannesmann-Werke		1			33	46	2700				
Wohverwahrt Nammen, Vestag	17	35	1700	1600	1100	15	1500	10	5		500,000
Porta, Vestag	13	50	18,000	2300	1000	60	600	1	3		400,000
Christianeglück	22	3	300	150					3		
Grottenberg Mannesman Christiane Mannesmann-Werke	40	35	2500	750	150	75	2000		4		60,000
Eisenhardter Tiefbau, Vestag	30	210	3200	2110	500		900	10	10		500,000
Neue Hardt, Vestag	115	240	4400	4300	800		600	20	20		335,000
Pfannenberger, Vestag	80	950	5000	2500	500		500	20	5		240,000
Grosse Burg, Vestag	25	135	2300	2000	400		500	10	8		700,000
Eisenzecher Zug, Vestag	100	650	6800	4000	700		300	15	15		355,000
Total	4066	3825	131,050	44,060	17,518	204	33,050	208	302	200,000	8,722,000

The manganiferous ores in the Siegerland, Taunus, and Peine districts must, however, take first place in importance. The whole of the Siegerland deposits, along with the Dr. Geier mine in the Taunus district, will possibly be required for the production of ferromanganese, leaving only the Peine ores and the Fernie mine output (Taunus) for the production of steel ingots. The production of the Bülten and Peine I/II mines is very limited, and therefore everything possible should be done to lower the use of manganiferous ores to the minimum.

The Amberg deposit has the advantage of being the richest iron ore in Germany, but the distances for transport to the Ruhr are so great that their use can only be justified by an exchange of iron ore for coal and coke. The losses in transport of the powdered form of the Pegnitz ore, and the long distances for transport would appear to rule them out. The phosphorus content of the ore is low as compared with the Salzgitter ores.

With the exception of the Pegnitz mine in Bavaria, the large and modern mines equipped with every possible time and labour saving device are all in the Salzgitter–Harz–Peine area, where the ore deposits are massive and cheaply mined, and the tonnages are large.

The ore bodies in the Siegerland are lenticular and small, and the costs of mining are high.

To a large extent the same applies to the old mines in the Lahn-Dill area.

Considerable tonnages, at reasonably low costs can be mined at the adit and open-cast mines in the Freiburg (Baden) district, and, provided transport on the Rhine is made available, the development of these ores may well be worth while. Likewise, mining operations in the Vogelsberg district are near the surface, and the washing of the ores is cheap and effective. These mines, along with the small mines in the Wesergebirge and Sauerland districts, have the advantage of being comparatively near the Ruhr, but the tonnages produced are small, the mines are scattered, and loading arrangements are not modern and rapid, as at Salzgitter ; also, all transport of ores must be by rail.

The present consumption of mine stores for the mines in the British Zone are summarized in Table XXIV.

Historical Note No. 3

A Cast-Iron Ring 2500 Years Old*

By Dr. H. R. Schubert†

In an article entitled "A Cast-Iron Ring 2500 Years Old,"[1] Professor K. Absolen, the founder of the Anthropos Institute of Czechoslovakia, describes a most remarkable discovery made in the extensive cave of Býčí Skála, north-east of Brno (Czechoslovakia). He discovered the remnants of a prehistoric smithy worked in the sixth century B.C. The material used was both bronze and iron. The iron products found at the smithy place were sickles, keys, hoes, nails, knives, bars, and—most interesting of all—*a ring of cast iron.*

On the smithy site was also found a mould, cut out of slate, intended for the casting of a wheel with four spokes and ornamented with bosses Whether the wheel was cast of iron or bronze cannot be determined, as no specimen has been found amongst the remains.

From the quantity of used-up tools discovered it may be inferred that ironworking had been going on for a considerable period ; that it ceased abruptly is shown by the many unfinished products. The sudden interruption was caused by the ghastly funeral sacrifice of a prehistoric chieftain and his suite which took place in the cave *circa* 600 B.C. Such circumstantial evidence strongly supports the inference that the ring was cast during the period in which the smithy was worked, but in view of the complete singularity of such a find a feeling of uncertainty as to this very early date cannot be avoided.

However, the gap in time would not be quite as big as that assumed. The casting of iron is not an invention as late as of the fourteenth century A.D., as is commonly supposed. There is historical evidence that the technique of obtaining liquid iron from a furnace, which consequently led to casting, was known in Europe in the eighth century A.D. at the latest, as is shown by various passages in a manuscript preserved in the Chapter's Library in Lucca (Italy).[2] This fact reduces the gap from 1,900 to 1,300 years. To obtain a further reduction, Professor Absolen's most valuable discovery may lead to further excavation of similar objects of cast iron at other places.

[1] *Illustrated London News*, 1946, vol. 209, Nov. 23, p. 592.

[2] Published (with transcription and translation) by J. M. Burnam in "A Classical Technology." (Edited from *Codex Licensis* 490.) Boston, 1920.

* Received 18th March, 1947.

† University of Reading.

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

ANNUAL GENERAL MEETING, 1947

THE SEVENTY-EIGHTH ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday, 14th May, 1947, at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1 (sessions at 10.0 A.M. and 2.15 P.M.), and on Thursday and Friday, 15th and 16th May, 1947, in the Lecture Theatre of the Institution of Civil Engineers, Great George Street, London, S.W.1 (sessions at 9.55 A.M. and 2.30 P.M. on the Thursday and at 10.30 A.M. on the Friday).

The whole of Wednesday, 14th May, was devoted to the discussion of a " Symposium on the Hardenability of Steel " (Special Report No. 36), a record of which will be found in the September issue of the *Journal*.

On the Thursday and Friday, Dr. C. H. DESCH, F.R.S., President of the Institute, presided at all the sessions. The record of the discussions follows this report.

The Minutes of the previous Meeting, held in London on 13th and 14th November, 1946, were taken as read and signed.

OBITUARY

The **President** (Dr. C. H. Desch, F.R.S.) : I have to report that we have lost by death an Honorary Vice-President of the Institute, Signor On Senatore G. E. Falck, and an Honorary Member of Council, Dr. J. W. Donaldson, President of the West of Scotland Iron and Steel Institute, both of whom died in January of this year.

The members stood in silence for a short time as a token of respect.

WELCOME TO MEMBERS AND VISITORS

The **President** : I should like to offer a welcome to the members and visitors attending this meeting. We are glad to see such a good attendance, and we hope that the Institute will now be able to resume the international relations which were so important before the war. Certain of the developments will be announced later.

Among the visitors here we have several members from Luxemburg, including His Excellency M. Andrew Clasen, the Minister for Luxemburg, who is an Honorary Member of the Institute, and M. Aloyse Meyer, the President of the Luxemburg Institute and an Honorary Vice-President of this Institute. (*Applause.*) One or two of us hope to attend the next important meeting of the Luxemburg Society. We are always glad to have some representation from France, and on this occasion we have MM. Dupuy and Bastien and one or two others. From Norway we have Mr. Muller, President of the Norwegian Metallurgical Society. We have now made arrangements to collaborate with that Society. (*Applause.*) From Sweden we have Mr. Sven Fornander, a name well known to those who have had connections with the Swedish industry, and Mr. E. von Hofsten. We have a number of Spanish visitors, among whom I should mention Señor Barreiro, who has been a very regular attender at our meetings. From Czechoslovakia we have Dr. Janicek, who is often to be found at meetings in different countries ; to whatever country I go I always meet him. Our Polish friends include Dr. Balicki and Dr. Wrażej, who have been working in this country.

There is one other visitor from oversea whom I should mention, Professor Robert Durrer, from Switzerland. We are holding our Summer Meeting this year in Switzerland, and that involves many complicated negotiations on the part of our own officials and certain Swiss members. In all these arrangements Professor Durrer has been particularly helpful. We are looking forward to a good meeting, and we are greatly indebted to Dr. Durrer for what he has done and is doing in making the arrangements for that meeting. At the Council meeting yesterday it was unanimously agreed to

make him an Honorary Vice-President of this Institute. (*Applause.*)

Report of Council and Statement of Accounts for 1946

The **President**: I now pass to the Report of Council, which has been printed, and which this year has the honour of a coloured cover. The growth in membership has been outstanding; the figures are given in the Report, and you will see that the increase has been very large.

Our arrangements with the British Iron and Steel Research Association have now been completed, and the Joint Research Committees, which have been operating very successfully for some time, have been taken over by the Association. We, however, continue to undertake all the publication for them, and certain of the information services. The relations between ourselves and the Association are very cordial, and Sir Charles Goodeve is one of our active members.

The Iron and Steel Engineers Group, which was formed recently, has been very successful. The meetings have been exceptionally well attended, and at these large meetings the engineering problems of iron and steel works have been discussed. Mr. Cartwright, the Chairman of the Group, has been most active and efficient.

The Library and Information Services have been developed, and certain important changes are going on, which will be reported later.

On the educational side we have had several matters to deal with. There is a Joint Committee on National Certificates in Metallurgy, and an Education Officer has been appointed.

You have seen the new form of the *Journal*, and I hope that it will be appreciated. It is now being published with great regularity, and, although the officers of the Institute have considerable trouble in ensuring supplies of paper, and so on, I think it is generally agreed that the *Journal* as now produced is a credit to the Institute. (*Applause.*)

We have been developing relations with the affiliated local societies and with a number of metallurgical societies on the Continent and in America. It has been possible to arrange for visits from one society to another, keeping up the connection and strengthening the ties between these various bodies.

I have now to report certain changes which are to be made. For some time we have had a joint secretaryship with the Institute of Metals. The Council of the Institute of Metals now think that the amount of work is such that they are bound to have their own separate secretary, and therefore Mr. Headlam-Morley ceases to be Secretary of the Institute of Metals. He is also Secretary of the Institution of Metallurgists. The new arrangements have been made in the most friendly way, and the members of the Institute of Metals have expressed their indebtedness to Mr. Headlam-Morley for the work that he did during the few years for which he held both offices. The change will not make any difference to the relations between the two bodies and to the co-operation between them. That co-operation is most important, because metallurgy is one science, although for convenience it is divided between two groups of metals. The working arrangements and the arrangements regarding subscriptions, the Library, and so on, will remain as before.

We are now inviting applications for grants from the Carnegie Research Fund. There will be two kinds of grant. There will be grants in aid of research, as hitherto, but the amounts will be increased so that the maximum amount of any individual grant will not normally exceed £250, and smaller grants will be awarded when suitable. It has been found necessary to revise the older arrangements on account of the increased cost of living in many areas where students go to work. It is proposed also to give one or two Travelling Carnegie Scholarships each year. The amount will vary in accordance with the requirements of each case, but will be generally of the order of £500, although it may be necessary on quite exceptional occasions to go even beyond that figure. The particulars will be announced soon. These travelling scholarships will probably involve in most cases travel across the Atlantic, so that naturally a larger sum will be required than for the ordinary scholarships.

The arrangements for the Mond Nickel Fellowships have now been made, with the money given by The Mond Nickel Co., Ltd., and applications are invited by the Committee, which consists of representatives of the Company and of the five metallurgical institutes. The Fellowships will normally be of the order of £750 a year.

The Institute has every prospect of increasing in prosperity with the resumption of normal conditions in the steel industry. Those who are in the steel industry will, I think, agree that conditions are not yet quite normal, but on the scientific side the developments are likely to be so considerable that the usefulness of this Institute will certainly increase.

I now beg to move that the Report of Council and the Statement of Accounts for 1946 be adopted. I will ask the Honorary Treasurer to deal with the Accounts.

The **Honorary Treasurer** (The Hon. R. G. Lyttelton): I have the honour to submit the Accounts, which you will find printed at the end of the Report of Council, on pages 496 to 500 of the April issue of the *Journal*. They are in the

usual form, except that this year there is an additional table at the end, where the expenditure and the income of the departments are tabulated in separate form. Now that such departments as the Publications Department have reached such large dimensions it was thought that it would be useful for members to see what their position was as regards their particular income and their particular expenditure. Otherwise, the Accounts are in the same form as before.

There are a few points on which I should like to touch. Our reserves, as you may remember, during the last six years have been increased by £10,000, with the object of having money available to spend when the more dormant war-time period ceased. We are now in times of so-called peace when we have developments afoot, and for 1946 we have spent, and for the next few years we expect to spend, a part of this £10,000 reserve in new developments for the benefit of members. The reason why I refer to this is that our expenditure for 1946 exceeded our income by £3,700, and this has been met by drawing from reserves. It has not meant drawing the full £3,700, because with one hand we have drawn the £3,700 out but with the other hand we have put into reserve no less than £1,150, owing to the usual principle, always adopted, of putting to reserve our entrance fees and life composition payments. The expenditure has therefore exceeded the income, but, notwithstanding that, I think that we may call the position quite satisfactory.

Several new additions have been made to the staff, and costs are therefore rising somewhat steeply, but at the same time income is also rising almost as sharply. The income is rising owing to the very remarkable increase in membership, and the remarkable increase in the sales of publications. Moreover, the Institute, as the President has said, carries on a large amount of work for the British Iron and Steel Research Association, which the Institute very much appreciates carrying out. It is work which we are glad to do, and we appreciate also the payment which B.I.S.R.A. makes for the same! We are also indebted to the many companies, mentioned in the *Journal*, who have agreed to continue their special subscriptions for another three years.

The *Journal* will take a little time—perhaps a year or two—to get fully into its stride. In the meantime, that requires financing, together with the other developments mentioned by the President; but, as you will see, last year was a year of great activity by the Institute, and this year is a year of still further activity at 4, Grosvenor Gardens and outside in the provinces.

I should like to draw attention to the very greatly increased sums of money, relatively to the past, with which we now deal. I appreciate the close attention which is paid to our finances by the Council, by the Secretary, by Miss Dowd (the Chief Accountant) and by the staff generally. I appreciate their services very much.

The motion for the adoption of the Report and Accounts was put by the President and carried unanimously.

Presentation of the Bessemer Gold Medal for 1947 to Sir William Larke, K.B.E.

The **President**: We now come to the presentation of the Medals awarded by the Council of the Institute. The first, the highest honour which we can award, is the Bessemer Gold Medal, a long-established honour, and one in connection with which we have a long list of very distinguished recipients. On this occasion the Medal is awarded to Sir William Larke. (*Applause.*)

Sir William Larke is known to most of you. He began his career as an electrical engineer associated with the British Thomson-Houston Co., Ltd. Later, he worked in the Ministry of Munitions, and did most valuable work during the first world war, as Director of the Dilution Section in 1917, Chairman of the Committee on the Utilization of Surplus War Material, 1919, Controller for the Disposals Board, 1919, and was connected very closely with the important question of disposal of materials after that war, being afterwards appointed Director-General of Raw Materials, 1919 to 1922.

From then until last year he was the Director of the British Iron and Steel Federation, and it is in that connection that most of us have been associated with him. Many will remember his work in the first world war, but this post which he held in the Iron and Steel Federation gave him one of the leading positions in connection with the iron and steel industry. We have always been delighted to carry on negotiations with Sir William Larke. He has also been a most faithful member of this Institute, and a most valuable Member of Council. It is therefore with particular pleasure that the Council, and I on their behalf, have the opportunity of presenting to Sir William Larke the highest honour which we can bestow, the Bessemer Medal.

The President then, amid applause, handed the Medal to Sir William Larke.

Sir **William Larke**: You will expect that words would almost fail me to express my gratitude to you all, and to the President and the Council in particular, for the very great honour which they have done me in awarding me the Bessemer Medal. I am fully conscious that I do not deserve it. It is a tribute more to the work of those with whom I have worked over a long period of time. No man has ever been more blessed than I have been in those who have been associated with me

in the many tasks in various fields of endeavour in which it has been both my pleasure and my honour to be engaged over what is now a long working life, and I should like to make a few acknowledgments.

The first, as you may expect, is to my wife and family. I have led a somewhat exacting life from the family point of view. My wife, with the greatest unselfishness, has been content to try to restore the exhausted energies of a man who would not spend them, when restored, in the family circle, but would simply go back to exhaust them again in work which was to him the whole spice of life, but to them could only be a rather tiresome interference with what they had a right to expect from the head of the family. I do express my deepest gratitude to them, because I am well aware that I could not have continued the various efforts which I had the pleasure of exerting without that devotion and care which I have received. In that I have been more fortunate than words can express.

The other acknowledgments that I want to make are more official. I should like to remind you that this work for which you have particularly awarded me the Medal, in connection with the research activities of the industry, was started in 1924, when the late Mr. Mannerberg was very much impressed by the initiation by the German iron and steel industry of the Wermestelle, and he discussed it with me. I was very keen, having been brought up in an industry which was based on almost day-to-day research, and having myself, from the age of 20 onwards, been engaged in a good deal of technological research. In fact, I remember at the age of 20 saying that I did not care who had to deal with the money side of industry or the commercial side; the technical and scientific side would suffice for me so long as I could find enough money to keep myself going and clothe myself with reasonable respectability! But we all know—those of us who have had a long working life, that is—that it is true that "there is a destiny that shapes our ends, rough-hew them how we will." I rough-hewed mine in certain directions, but destiny certainly took charge and pushed them in entirely different ones, and I do not regret it.

It is to the late Mr. Mannerberg, however, that we owe the initial enthusiasm. The industry was not very enthusiastic at that time, and I well remember one of my friends, with that great attribute of friendship, complete candour, saying to me, after Mr. Mannerberg and I had induced a small committee to work with us on the question of fuel economy—a committee which ultimately was converted into the Iron and Steel Industrial Research Council—"You do not really think that you can teach us our business?" I said, "Good Lord, no! What we hope is that you will teach us to be more useful to the industry." That was in fact the case.

That fuel committee was ultimately converted into the research organization, with Mr. E. C. Evans as the chief technical adviser. I should like to pay a tribute to him which is thoroughly deserved, because he joined us as a fuel and combustion chemist, and when we extended the area of the work he adapted himself with remarkable ability to a very wide range of scientific inquiry, always being conscious of his own limitations. I think you will all agree that he pursued the crusade which I tried to inspire in the industry with great urbanity, and received general acceptance. We owe him a debt of gratitude.

That small organization, and the two or three of us who were so enthusiastic that nothing could discourage us, were only the catalyst which brought a number of isolated individual elements together, and ultimately by their own efforts and consciously they merged into a corporate whole, of which the iron and steel industry can well be proud; because I believe that your Research Association today is one of the finest examples in the whole world of a corporate activity on the part of a major industry.

That is something for which I am indeed grateful. Very few men have seen so many of their dreams come true, and it has all been due to those with whom I have been associated. It is now more than forty years ago since I first had any technological connection with the iron and steel industry, and I am delighted to see my old friend and colleague, G. M. Brown, here, because he and I persuaded Messrs. Dorman, Long & Co., Ltd., to put in the first electrically driven rolling mill in this country. That is not literally true; they had two contracts to place, and they placed the first one in Germany, because the only mill in the world at that time was the one that the Germans had. I persuaded them to get the second one, for which they placed the contract within a few weeks, here. I pointed out that we should never do anything unless somebody gave a lead; somebody had to do it first. I persuaded them with the help of beating the German price by about 15%; I think that was a major factor! The fact remains that while we had ten days of teething troubles our German competitors were six to eight weeks behind in getting started, and that justified the confidence which Dormans were good enough to place in us. From that day onwards electrical equipment for the British iron and steel industry went fairly rapidly forward. That was not entirely due to us; others contributed very largely, including Mr. Rothera and his company in those days.

I do not want to talk too much of the past, but

I want to make one other personal acknowledgment, to Mr. (later Sir) John Craig, who has kindly come here today to take part in these proceedings. He was the first President with whom I worked in 1922, and he guided my halting footsteps through the mazes of the industry, which after all, and quite naturally, was a strongly individualistic one. That individualism had to be overcome, and you now have an industry which has so organized itself, economically as well, as to be able to act as a unit in the national economy; and, when we remember that this industry is the foundation of all others, I think that there is nothing more important or more encouraging for the ultimate solution of our present difficulties than the fact that this great industry was organized and equipped on such a basis, recognizing as it does, and as it has done for many years, that its own best interest is served to the extent that it can serve the national interest. That is one of the greatest factors for encouraging us to believe that we shall ultimately triumph over present difficulties.

I speak now as one of the older men, though I am hardly prepared to admit it. Older men are allowed to see visions, but the young men are expected to dream dreams, and to make their dreams come true. There are a few questions about which I venture to suggest to you that something must be done. I know that you always expect that when I speak to you I shall have something to say about my fancies, whatever you may think of them.

I feel that one of the most important problems for this industry, and one to which we have devoted a great deal of time, is corrosion. I want to make an appeal for a new attack on that problem by young men. I say "young men" advisedly, and I mean young men from 25 to 35, because they are much more enthused about the objectives and much less inhibited about the difficulties of reaching them. As we get older, we know too much about the difficulties.

I try to rule the word "impossible" out of my dictionary. It is not stupid to do so as long as you do so with the consciousness that you have a good reason for so doing in any problem that you approach. It is not only healthy but our duty to rule it out. That very intractable problem must be solved. I drew up the dictum that an engineer is a man who can do for one pound what any fool can do for two, and I have tried to follow that. I think that it is the only justification for our technological advice on which expenditure is based. We hear a good deal about people wanting more and more for less and less, but we as an engineering and technological industry have to produce more and more from less and less. That is one of the roads which we must follow to overcome our present difficulties.

In that regard, I want to appeal to the engineering side of our industry and to the designers to use our steel more economically, to try to save that 10 or 15% which I believe is possible by the utilization of welding wherever it is applicable, to consider the use over a much wider field of higher-tensile steel and thus reduce the weight required for a given service, and above all to give consideration to methods of design which I am sure have the potentiality of saving another 25%.

I wish that I were thirty years younger; the immediate future is so full of interest. To you young men may I say, "Go to it! Good luck to you! And, above all, thank you!" (*Applause.*)

Presentation of the First Sir Robert Hadfield Medal to Dr. J. H. Chesters

The **President**: The honours which the Institute can confer have been added to by the Sir Robert Hadfield Medal. This is the first occasion on which we have been able to award this Medal, and it has to be awarded today in token form, because the medal itself is not yet ready. It is awarded to Dr. J. H. Chesters in recognition of his work on refractories for the use of the iron and steel industries and of his share as co-author in preparing Special Report No. 37 (1946) on "The Influence of Port Design on Open-Hearth Furnace Flames."

I remember him very well as a student in Sheffield University, and I remember the work which he did then with Dr. Reeve. He held a Metropolitan-Vickers Research Scholarship, and did valuable work in the study of refractories. He has had experience not only in this country but abroad. He worked for a time at the Kaiser Wilhelm Institute in Berlin-Dahlen, and then in the United States of America in the University of Illinois. He has really an unequalled knowledge of the scientific side of refractory materials, and we had no hesitation in awarding him the first Sir Robert Hadfield Medal.

The President then, amid applause, handed the certificate to Dr. Chesters.

Presentation of Andrew Carnegie Medals

The **President**: We have now been able to resume the awards of the Andrew Carnegie Medals. The Silver Medal for 1945 has been awarded to Dr. Ing. M. Balicki for his memoir on "A Study of Work-Hardening and Re-Annealing of Iron."* We were familiar before he came to this country with some of his publications in a somewhat difficult language, Polish. The work which he did at University College,

* *Journal of the Iron and Steel Institute*, 1945, No. I, p. 181P.

Swansea, is very excellent. I had the pleasure of examining that work when he prepared it for submission for a degree, and I can speak of it as an excellent piece of experimental work, admirably presented. I am therefore very glad to hand the Carnegie Silver Medal for 1945 to Dr. Balicki. (*Applause.*)

The Andrew Carnegie Gold Medal for 1946 is awarded to Mr. H. Morrogh for his memoir on "The Neutralization of Sulphur in Cast Iron by Various Alloying Elements."* Mr. Morrogh has published a number of papers of very great value. Those who have had occasion to work on cast iron will know that the metallographic side of this study is not a very easy one, and the improvements which have been made in the published photographs of cast iron by Mr. Morrogh are entirely outstanding. I was going to say "improvements in technique," but I stopped myself, because when I saw Mr. Morrogh and read his papers I found that his technique did not differ very much from that used by other people, but he was able to obtain results which none of us could get. Most of us, if we have to prepare a cast-iron specimen, tear out a good deal of the graphite in the specimen and leave a lot of holes, but Mr. Morrogh is able to preserve every detail, and the marvellous photographs which he has published are a great testimony to his own skill, and are of the greatest value to everyone associated with the study of cast iron. I have much pleasure in presenting him with this Gold Medal. (*Applause.*)

Presentation of a Williams Prize for 1946

The **President**: The Williams Prize for 1946 is awarded jointly to Dr. B. Jones and Mr. I. Jenkins for their paper on "The New Annealing Plant for Steel Strip in Coils at the Whitehead Iron and Steel Co., Ltd., Newport, Mon."† The Williams Prize is given for a practical paper, and this paper gave an admirable description of a new and very fully developed plant which has been erected in recent times. I happen to have a very close acquaintance with this plant and know the great care taken by the two authors in the preparation of this paper, so that it gives me great pleasure to present them with this prize. (*Applause.*)

Changes on the Council

The **Secretary** (Mr. K. Headlam-Morley): I have to report the following changes on the Council since the last General Meeting in the autumn:

New Vice-Presidents: Mr. W. B. Baxter, Mr. H. H. Burton.

Honorary Vice-President: Professor R. Durrer.

New Members of Council: Mr. D. A. Oliver, Mr. F. Saniter, Dr. C. Sykes, F.R.S.

Honorary Member of Council: Mr. T. F. Russell, during his period of office as President of the Sheffield Metallurgical Association, in succession to Mr. H. Bull.

In accordance with Bye-Law No. 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1946, as being due to retire at the present Annual Meeting:

Vice-Presidents: Captain H. Leighton Davies, Mr. J. S. Hollings, and Mr. G. H. Latham.

Members of Council: Mr. R. A. Hacking, Mr. H. H. Burton, Mr. Desmond Lysaght, Mr. N. H. Rollason, and Mr. D. F. Campbell.

As Mr. J. S. Hollings has been nominated an Honorary Vice-President and Mr. H. H. Burton has been elected a Vice-President, and Mr. D. Lysaght has resigned from the Council, Mr. R. Mather (Vice-President), Sir Arthur Matthews, and Mr. J. Sinclair Kerr (Members of Council) become due to retire in their stead.

No other members having been nominated up to one month previous to the present meeting, the retiring Vice-President and Members of Council are now presented for re-election.

The **President**: In accordance with our Bye-Laws, I declare them re-elected.

Ballot for the Election of Members and Associates

Mr. James Mowat (Glasgow) and Mr. J. Thomson (Glasgow) were appointed scrutineers of the ballot for the election of Members and Associates, and in due course reported that the following 269 Members and 123 Associates had been elected.

Members

Acock, George Percival, B.Sc., A.R.I.C. (Birmingham). **Adair**, Thomas Howard, M.Sc., B.Sc. (Ontario, Canada). **Adam**, William Atkinson, A.M.I.Mech.E. (Buenos Aires, Argentina). **Adamson**, Matthew (Stockton-on-Tees). **Alcock**, John F., M.A. (Leeds). **Ali**, Mir Asad, M.Sc. (Manchester). **Allan**, George William Crawford, Ph.D. (Worcester Park, Surrey). **Arnett**, Timothy (Darlaston). **Astbury**, Norman Frederick, M.A., F.Inst.P., A.M.I.E.E. (Wolverhampton). **Austin**, James B. (Kearny, N.J., U.S.A.). **Baeza**, Professor Pedro Gómez (Madrid). **Bailey**, Ronald William, M.A., B.Sc. (Oxford). **Baker**, Bernard, M.A., A.C.A. (Rotherham). **Bakes**, John Leslie Michael (Leeds). **Banks**, John Thomas (Mossley, Manchester). **Bartocci**, Professor Aldo (Terni, Italy). **Bashir**, Sheikh Mohamed, B.Comm. (Cawnpore, India). **Batcheller**, Hiland G. (Pittsburgh, Pa., U.S.A.). **Baxter**, Gordon (Glasgow). **Bell**, Henry George (Briton Ferry, Glam.).

* *Journal of the Iron and Steel Institute*, 1946, No. II.

† *Journal of the Iron and Steel Institute*, 1946, No. II, p. 163P.

Bennett, Reginald S., A.M.I.Mech.E., M.I.E.E. (Sheffield). **Berthier**, Paul Maurice (St. Chamond, Loire, France). **Biggin**, Harold (London). **Binder**, William Oakley, B.S. (New York). **Bird**, William Knowler (Leeds). **Birkin**, Charles Pearce (London). **Borland**, James McAulay (Motherwell, Lanarkshire). **Bowden**, Andrew Thomson (Newcastle-upon-Tyne). **Brooke**, George Edwin (London). **Brooks**, Cyril (Darlaston). **Brooks**, Frederick Harold (Darlaston). **Brown**, David, M.I.Mech.E., M.I.A.E., A.F.R.Ae.S. (Huddersfield). **Brown**, Marshall H., Ph.D., M.S. (Wilmington, Delaware, U.S.A.). **Brown**, Norman Benjamin, B.A., Sc. (Ontario, Canada). **Brown**, Reginald George (Manchester). **Buchanan**, Thomas Alfred, D.S.O., M.C., B.Sc. (Sheffield). **Burnett**, Jack (Stocksbridge, Sheffield). **Caddick**, Harry (St. Helens, Lancs.). **Calvert**, Frank (Leeds). **Cameron**, Robert (Paisley, Renfrewshire). **Caney**, Richard John Trewhitt (London). **Carr**, Harry, B.Sc. (Sheffield). **Carruthers**, Tom (Workington, Cumberland). **Cartwright**, James (Manchester). **Castro,** René J. (Ugine, Savoie, France). **Challansonnet**, Jean (Suresnes, Seine, France). **Chang**, Pei-Lin, B.Sc. (Sheffield). **Chapman**, John (Sheffield). **Chichmanian**, Yervant (Bacos Ramleh, Egypt). **Chowdhury**, Bhim Bhowani Roy, B.Sc. (Khargpur, Bengal, India). **Chung**, Heung-Sung, B.A. (Sheffield). **Clamp**, George William (Darlaston). **Clark**, Alan P., B.Sc. (Scunthorpe, Lincs.). **Clark**, Ronald (New York, U.S.A.). **Clipstone**, Geoffrey Hugh (Rugby). **Collen**, Torsten A. (Kallinge, Sweden). **Cook**, Reginald Massey, B.Sc. (Stocksbridge, Sheffield). **Coombs**, Arthur George Hywel, B.Sc. (London). **Corbett**, George Felix (Rotherham). **Crankshaw**, Fred (Stocksbridge, Sheffield). **Cude**, Arthur Leslie, B.Sc. (London). **Cullen**, Edward (Coxhoe, Co. Durham). **Cumber**, Charles Whitfield (London). **Dass**, J., B.Sc. (Jaipur, Rajputana, India). **Daum**, Leon (Paris). **Davies**, Abiah Glyn (Pontardulais, Swansea). **Davies**, David Leslie, A.M.I.Mech.E. (Rotherham). **Davies**, Max Emil, B.A. (London). **Davis**, John Vivian Percival (Morriston, Swansea). **Davis**, Roy H. (Welland, Canada). **Day**, Harold John Terrett (Birmingham). **Day**, Julian Wentworth (Walsall, Staffs.). **DeDecker**, H. C. J., D.Sc. (Amsterdam, Holland). **Demerbe**, Georges (Mons, Belgium). **Denaro**, Louis Frederick (London). **Des-Raj**, James Ivan, B.Sc., A.M.I.Mech.E. (Darlaston). **Diaz-Pedregal Garcia deTunon**, Jovino (Madrid). **Douglas**, Adam, A.I.M. (Glasgow). **Durand**, Jean (Paris). **Eccles**, Alexander Herbert Lindsey (Neath, Glam.). **Edwards**, Alun, Ph.D., B.Sc. (Sheffield). **Ellis**, Ernest Bower (Jarrow-on-Tyne, Co. Durham). **Eva**, Victor Worsley (Manchester). **Falkingham**, Arthur Ferdinand (Altrincham, Cheshire). **Felgate**, L. J. (London). **Fisher**, Robert Edward Snow, M.C., M.Inst.C.E., A.M.I.E.E. (Sheffield). **Fletcher**, Frank, B.Sc., A.M.I.Mech.E. (Huddersfield). **Fowler**, Eric Farquharson (East Molesey, Surrey). **Fox**, Francis Arthur, M.Sc., F.I.M. (London). **Franke**, Richard Hugh, A.M.I.Mech.E., A.M.I.P.E. (Coventry). **Frisell**, Gosta (Stockholm). **Geach**, George Alwyn, Ph.D., M.Sc. (Sale, Cheshire). **Gilmore**, Edward, J., B.S. (Cleveland, Ohio, U.S.A.). **Glass**, Harold Marks, Ph.D., M.Sc., F.R.I.C. (Worksop, Notts.). **Goyns**, Hugh Glover (Derby). **Graham**, Ronald (East Moors, Cardiff). **Griffiths,** Isaac Thomas (Port Talbot, Glam.). **Grison**, Marcel (Longwy, France). **Gutierrez**, Antonio de Calatayud (Santander, Spain). **Hall**, John Reginald (Stoke-on-Trent). **Hallsworth**, John William, M.B.E. (Scunthorpe, Lincs.). **Hanson**, Victor Cyril (Slough). **Harber**, Harry, B.Sc. (Port Talbot, Glam.). **Harding**, John (Chicago, U.S.A.). **Harris**, Geoffrey Thomas, M.A., F.Inst.P. (Sheffield). **Harvie,** John Allan Pollock (Kettering, Northants.). **Hawdon,** George Ainsworth (London). **Haywood**, Laurence John Arthur (Leeds). **Heppenstall**, Reginald John (Rotherham). **Herne**, Howard (London). **Hessenberg**, W. C. F., M.A., F.I.M. (London). **Hickman**, William Westwood (Wolverhampton). **Hight**, Jack R. (London). **Hjerdin**, Sven (Luleå, Sweden). **Hoare**, Edward Graham, A.M.I.C.E. (Port Talbot, Glam.). **Hobson**, Harold John (Stocksbridge, Sheffield). **Holmes**, John Grant, A.M.I.Mech.E. (Sheffield). **Holmes**, Thomas Henry (London). **Hotchkiss**, Henry Bushell (Stocksbridge, Sheffield). **Hothersall**, Arthur Wesley, M.Sc., F.I.M. (London). **Hoyland**, George Eric (Stocksbridge, Sheffield). **Hsu**, Li-Chang, B.Eng. (Sheffield). **Hughes**, Emrys (Landore, Swansea). **Huitson**, Robert Ross (Rugby). **Hutton**, William (Corby, Northants). **Idle**, Robert William (Stockton - on - Tees). **Inman**, Oliver (Stocksbridge, Sheffield). **Ivett**, Percy (Birmingham). **Jamison**, Robert James (Stockport, Cheshire). **Jeffes**, James Henry Elliston (London). **John**, Leslie (Gorseinon, Glam.). **Jones**, Noel Henry (Bulawayo, S. Rhodesia). **Jones**, Raymond Nicholson (Port Talbot, Glam.). **Jones**, Stanley Vance (Port Talbot, Glam.). **Kern**, Paul (London). **Kerry**, Dennis, A.M.I.Mech.E. (Port Talbot, Glam.). **Khan**, Gulsher Mohammad (Aston, Birmingham). **Kilby**, John Arthur (Motherwell, Lanarkshire). **Knight**, Harry Jack (London). **Krishnappa**, Tippanna, M.Sc. (Sheffield). **Laird**, Robert (Port Talbot, Glam.). **Langner**, Alan John B.Met. (London). **Lennox**, James William (Sutton-in-Ashfield). **Leonard**, Leslie George Adye (Levenshulme, Manchester). **Liddiard**, Edwin Andrew Guthrie, M.A., F.I.M. (Stoke Poges, Bucks.). **Lord**, George William (Aldershot, Hants.). **Ludwig,** John N., jun., B.Sc. (Pittsburgh, Pa., U.S.A.). **Lumsden**, Frederick (Arbroath, Scotland). **Lunt**, George Ernest (Darlaston). **McCrosson**, James

(Motherwell, Lanarkshire). **McCumiskey**, Arthur Vincent (Darlaston). **MacKenzie**, James Tucker, jun., B.A., M.S. (New York, U.S.A.). **McMulkin**, Francis John, B.S., M.E. (Ontario, Canada). **Mainwaring**, William Gwynne, B.Sc. (Port Talbot, Glam.). **Martin**, S. W. (Hollingwood, Chesterfield). **Maton**, Horace Frank, A.M.I.Mech.E. (London). **Mayo**, Warren H. (Pittsburgh, Pa., U.S.A.). **Mead**, William Henry (London). **Mears**, Robert Bruce, Ph.D., B.Sc. (Pittsburgh, Pa., U.S.A.). **Messner**, Otto Hans Caspar, D.Sc.Tech. (Zurich, Switzerland). **Meunier**, Professor Francis A. (Mons, Belgium). **Meyrick**, Trefor Gwynn, B.Sc. (London). **Millar**, Robert Hunter (Coatbridge, Lanarkshire). **Miller**, George Leslie, Ph.D., A.R.I.C., F.I.M. (Rainham, Essex). **Millington**, Leslie George (London). **Mills**, George Leslie (Dagenham): **Morris**, Sydney, A.I.M. (Middlesbrough). **Moss**, William Eric (Port Talbot, Glam.). **Muller**, Brostrup Marius (Oslo). **Mumford**, L. Quincy (Cleveland, Ohio, U.S.A.). **Murray**, James (Middlesbrough). **Napier**, James (Saltburn-by-the-Sea, Yorks.). **Newman**, Lynn Valentine (Port Talbot, Glam.). **Nixon**, Sir Frank Horsfall, K.C.M.G., C.B. (London). **Olander**, Professor Arne, Ph.D. (Stockholm). **Ormandy**, George (Stockton-on-Tees). **Orowan**, Egon, D. Eng., F.R.S. (Cambridge). **Owen**, Bernard George (Rugby). **Padget**, **Geoffrey** (Stocksbridge, Sheffield). **Parkin**, Frank Leslie, B.Sc., A.M.I.E.E., A.M.I.Mech.E. (Sheffield). **Pendred**, Benjamin Wildig, M.I.Mech.E. (London). **Pick**, Harold George (Port Talbot, Glam.). **Pingault**, Pierre Felix (St. Chamond, Loire, France). **Pinot**, de Villechenon Jacques (Paris). **Pool**, William John (Rugby). **Pope**, Donald Eric (Darlaston). **Powell**, Charles L. (Redcar, Yorks.). **Powell**, Daniel (Gorseinon, Glam.). **Price**, Richard Henry (West Hartlepool). **Pritchard**, R. (Stoke-on-Trent). **Proctor**, Robert Gordon (Saltburn-by-the-Sea, Yorks.). **Rastrick**, Professor Ronald John, B.E.(Mech.) (Christchurch, New Zealand). **Rees**, William Stanley (Port Talbot, Glam.). **Reichwald**, O. F. (Basle, Switzerland). **Remy**, Gilbert (St. Chamond, Loire, France). **Revel**, Pierre (Paris). **Rice**, Warner G. (Michigan, U.S.A.). **Roberts**, Leonard Vickers, A.M.I.E.E. (Darlaston). **Roberts**, Rowland Spencer (Corby, Northants). **Robertson**, Willie Reid, A.M.I.Mech.E. (Darlaston). **Robinson**, Arthur Alexander, B.A. (Stafford). **Rockett**, George Kirk (Risca, Mon.). **Rodger**, Comdr. R. H. S., O.B.E. (London). **Roe**, William Leslie (Derby). **Royer**, Charles (Le Boucau, Basses-Pyrenees, France). **Rushton**, George Ivor (Newport, Mon.). **Sandham**, William, A.M.I.Mech.E., M.Inst.F. (London). **Scott**, Eric Kenneth, B.Sc.Eng. (Middlesbrough). **Senior**, Sydney (Mossend, Lanarkshire). **Shankar**, Mysore Basaviah, M.Sc. (New Delhi, India). **Sharma**, Professor Anand Swarup, B.Sc. (London). **Sharp**, William Henry (Rodley, Leeds). **Shorter**, Alfred John, M.Sc., A.R.I.C., M.Inst.F. (Bonnybridge, Stirlingshire). **Siverns**, Joseph H. (Gowerton, Swansea). **Skelly**, Hugh McKenna, Ph.D., B.Sc., A.R.I.C. (Wolverhampton). **Slade**, Miss Isabella Minto, M.Sc. (London). **Smith**, Laurence, B.Sc.Eng. (Met.), A.I.M. (Billingham, Co. Durham). **Smith**, Ralph Colin (London). **Smith**, Stuart Jervis (Croydon, Surrey). **Snow**, Henry Alan (London). **Soward**, Norman H. (Port Talbot, Glam.). **Sprankle**, A. F., B.Met.Eng. (Canton, Ohio, U.S.A.). **Stallard**, Charles, A.M.I.Mech.E. (Darlaston). **Stanners**, John Francis, B.Sc. (Birmingham). **Stock**, Aubrey Ernest (Port Talbot, Glam.). **Summers**, John William (Middlesbrough). **Sutton**, William (Darlaston). **Symonds**, Alfred (Chesterfield). **Tasker**, Cyril James (Port Talbot, Glam.). **Tennent**, James Norman (Coatbridge, Lanarkshire). **Thibaut**, Ch. G. (Longwy, France). **Thomas**, John Bernard (Sheffield). **Thornely**, Bernard Norman Heath (Banbury, Oxon.). **Timmins**, Arthur Alfred, F.R.I.C., A.I.Mech.E., A.I.M. (Netherton, Worcs.). **Timmis**, Arthur Brian (Darlaston). **Torneman**, Yngve (Surahammar, Sweden). **Toye**, Ronald, B.Sc., A.M.I.E.E. (Swansea). **Treasure**, Reginald William (London). **Trotman**, Reginald Beveridge (Wolverhampton). **Vialle**, Jean Marie (St. Chamond, Loire, France). **Voice**, Ernest Wallace, B.Sc., A.Inst.P. (London). **Walker**, Clement Douglas Howard (Vereeniging, Transvaal, South Africa). **Ward**, William (Michigan, U.S.A.). **Watson**, Lt.-Col. Nigel, O.B.E. (Leoben, Central Mediterranean Forces). **Watson**, Robert (Mossend, Lanarkshire). **Webb**, Clarence Leslie Albert (East Molesey, Surrey). **Welch**, Lawman (Scunthorpe, Lincs.). **Westley**, Jens (Hardanger, Norway). **Whitaker**, Frank Cecil Norman (Sheffield). **Wild**, William, M.A. (Attercliffe, Sheffield). **Wilde**, Thomas Haslop, B.A., A.R.I.C. (London). **Wilks**, Leslie Philip (West Bromwich). **Willan**, Geoffrey Lawrence (Sheffield). **Williams**, Alan Vernon, B.Sc., A.M.I.Mech.E. (Port Talbot, Glam.). **Williams**, Derek Bule (Neath, Glam.). **Williams**, Joseph A. (London). **Williamson**, James Nicholas (London). **Williamson**, Dr. Merritt Alvin, B.E., M.S. (San Diego, California, U.S.A.). **Wills**, William Richard, L.I.M. (Ruddington, Notts.). **Wilson**, Arthur (Sheffield). **Wilson**, Thomas Warrington, B.Sc. (London). Wintrebert, Leon (Indret, Loire-Inférieure, France). **Wood**, Edward (Consett, Co. Durham). **Woodward**, Dennis Howard, B.Sc., A.R.I.C., A.I.M. (Corby, Northants.). **Work**, Harold K., Ph.D. (Pittsburgh, Pa., U.S.A.). **Wright**, Norman Percy, B.Sc. (Bristol). **Wrightson**, Peter (Thornaby-on-Tees). **Yapp**, Robert H., A.M.I.Mech.E. (Sheffield). **Young**, Andrew (Glasgow).

ASSOCIATES

Akroyd, Brian Anthony (Birmingham). **Allan**, James Fairgrieve (Manchester). **Andrew**, Alfred Tresham (Ipswich). **Andrews**, Douglas Roy (Bristol). **Aytekin**, Veli, B.Sc. (Edgbaston, Birmingham). **Baldwin**, Ernest, B.Sc. (Armley, Leeds). **Barleggs**, Roy Ernest (Letchworth, Herts.). **Baugh**, Trevor John (Shirley, Birmingham). **Bergmann**, Josef (London). **Binley**, Robert Charles (Corby, Kettering). **Bishop**, Dennis Edmund (Witton, Birmingham). **Booth**, Eric Donald Hilton (Stoke-on-Trent). **Brock**, Peter (Sheffield). **Brown**, Anthony Reginald George (Canton, Cardiff). **Brown**, Herbert Stuart (Stafford). **Brown**, Russell Harvey (Newcastle-on-Tyne). **Broxton**, Ernest Samuel (Birmingham). **Butler**, James Morris (Cambridge). **Caldicott**, John (Birmingham). **Campbell**, James William (London). **Cannings**, Raymond Gordon (Port Talbot, Glam.). **Carr**, Anthony Louis (Cardiff). **Carr**, Terence Osborne (Redditch, Worcs.). **Cashmore**, Wallis Partridge (East Moors, Cardiff). **Chakravorty**, Dilip Kumar, B.Met. (Calcutta). **Chatterjee**, Saurinda Nath Chattopadhyay, B.Sc. (London). **Clark**, Edwin Brian (Parkside, Coventry). **Clark**, Paul William (Sheffield). **Colner**, William Howard (Chicago, U.S.A.). **Cowan**, Arthur (Consett, Co. Durham). **Croom**, Edward Anthony Gunter (Cambridge). **Crosby**, Arthur (British Army of the Rhine). **Davidson**, Ian Richard (Durham). **Davies**, John Kenneth (Clifton Junction, Manchester). **Davis**, Alan George (Cambridge). **Dawson**, John Donald (Stockton-on-Tees). **Deeming**, Arthur Geoffrey (Staveley, Chesterfield). **Dixon**, Allan Hugh (Stockton-on-Tees). **Down**, Richard Francis (Swindon, Wilts.). **Draper**, Alan Richard, A.M.C.T., L.I.M. (Clifton Junction, Manchester). **Duckworth**, Walter Eric (Stafford). **Eccleston**, Anthony James (Birmingham). **Eisner**, Stephen Hugo (Wembley, Middlesex). **Ellis**, John Sidney (Scunthorpe, Lincs.). **Evans**, Elwyn Llewellyn (Middlesex). **Evans**, Howell Thomas (Swansea). **Evans**, Leslie George (Swansea). **Fear**, Geoffrey Charles (Bridgend, Glam.). **Ferendinos**, Speros (Que Que, S. Rhodesia). **Fleming**, R. P. H. (London). **Frankau**, Anthony McDougall, B.A. (Cambridge). **Frost**, Brian Reginald Thomas (Birmingham). **Fuller**, Frank Thomas (Sheffield). **Gad**, Gamal El-din Mohamed (London). **Ganapati**, Kattuputhur Subrahmanya (Durham). **Gardner**, Arthur George (Alvechurch, Birmingham). **Gibbons**, Donald Frank (Edgbaston, Birmingham). **Glick,** William Woolfe (Swansea). **Gregory**, Eric (Cambridge). **Grounds**, Donald Morley (Smethwick, Staffs.). **Hardwick**, Donald (Sheffield). **Harris**, John Geoffrey (Birmingham). **Hartland-Garratt**, Gordon (Birmingham). **Hickley**, Roger Hugh (Sheffield). **Holliday**, Kenneth Hedley (Manchester). **Holt**, Lawrence Guest (Holyhead). **Hooker**, Eric J. (Cambridge). **Hunt**, Alan Breeden (Wednesbury, Staffs.). **Jackson**, Richard S. (London). **Johnston**, Keith Bray (Southall, Middlesex). **Jones**, Noel John (Bridgwater, Somerset). **Kent**, Donald (Smethwick, Staffs.). **Kersting**, Philip Eric (London). **King**, Christopher Stanley (Rainham, Essex). **Leeworthy**, Frederick Charles Llanharan, Glam.). **Leonard**, John Francis Joseph (Cobh, Co. Cork, Eire). **Lilly**, John (Corby, Northants.). **Mackenzie**, John (Durham). **Madsen**, Peter Emil (Edgbaston, Birmingham). **Mead**, Harry Wilfrid (Sheffield). **Melia**, Austin (Stockton-on-Tees). **Metcalfe**, Arthur George, B.A., A.Inst.P. (Cambridge). **Mills**, J. F., B.A. (Cambridge). **Muller**, Lee (Que Que, S. Rhodesia). **Murray**, Peter Wood (Motherwell, Lanarkshire). **Oliver**, Dennis Stanley (Edgbaston, Birmingham). **Oliver**, Robert (Durham). **Osborne**, Cyril John, B.Met.E. (Bethlehem, Pa., U.S.A.). **Palmer**, Samuel Wallace, A.I.M. (Alvechurch, Birmingham). **Pester**, Dorothy Margaret (Birmingham). **Powell**, David Ronald (Llanelly, Carmarthenshire). **Pratt**, John Nevitt (Birmingham). **Prince**, Bernard Williamson (Penistone, Sheffield). **Pugh**, Gwilym (Blaenau Ffestiniog, Merionethshire). **Pyke**, John Albert (Stockton-on-Tees). **Randall**, M. W., L.I.M. (Coventry). **Rao**, Kilaru Nageswara (Cardiff). **Redfern**, Anthony Colin (Manchester). **Roblin**, L. D. (Port Talbot, Glam.). **Rogers**, V. A. B. (Bletchley, Bucks.). **Sandelands**, John (Workington, Cumberland). **Sen**, Debabrata, B.Met. (Calcutta). **Stephenson**, Joseph (Sheffield). **Stormont**, Ronald Stephen (Birmingham). **Sundback**, Paul Philip (Chelsea, Mass., U.S.A.). **Thomas**, David Lloyd, B.Sc. (London). **Thomas**, Frank M. (Swansea). **Thomas**, Ronald Walter, L.I.M. (Lockwood, Huddersfield). **Thomas**, William John (Llanelly, Carmarthenshire). **Truscott**, Peter (Swansea). **Tuck**, Michael John (Bishopston, Swansea). **Tucker**, Gerald Edward George (Hounslow West, Middlesex). **Vlantis**, Christian (Bulawayo, S. Rhodesia). **Walker,** Laurie, B.Sc. (Tech.) (Stafford). **Walker**, Thomas Henry (Workington, Cumberland). **Ward**, Lawrence (Methley, Leeds). **Warrior**, Thomas (Irlam, Manchester). **Weddle**, William Anthony (Newcastle-on-Tyne). **Williams**, George Henry Houghton (Swansea). **Williams**, John William (Alvechurch, Birmingham). **Williams**, Ronald Leslie (Neath, Glam.). **Wilson**, Graham Rudge (Stafford). **Woodfine**, Bernard Charles (Sheffield).

SECOND HATFIELD MEMORIAL LECTURE

The Second Hatfield Memorial Lecture was delivered in the Lecture Theatre of the Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday, 14th May, 1947, at 8.30 P.M. Dr. C. H. Desch, F.R.S., President of the Institute, presided.

Dr. C. Sykes, F.R.S. (Brown-Firth Research Laboratories, Sheffield), lectured on "Steels for Use at Elevated Temperatures." The text of the lecture will be found in the July issue of the *Journal*, pp. 321–369.

Members' Dinner

A dinner was held at the Connaught Rooms, Great Queen Street, London, W.C.2, on Thursday, 15th May, 1947, at 7.15 P.M. Dr. C. H. Desch, F.R.S., President of the Institute, was in the Chair and was supported by a number of Past-Presidents, Vice-Presidents, and Members of Council. Nearly five hundred members and guests were present; among the guests were: The Rt. Hon. Lord Cherwell of Oxford, P.C., F.R.S., the Rt. Hon. W. J. Jordan, P.C. (High Commissioner for New Zealand), the Rt. Hon. J. A. Beasley (High Commissioner for Australia), Mr. G. Heaton Nicholls (High Commissioner for the Union of South Africa), His Excellency Viscount A. O. de Thieusies (Belgian Ambassador), His Excellency Dr. Cheng Tien-Hsi (Chinese Ambassador), His Excellency M. Paul Ruegger (Swiss Minister), His Excellency M. A. J. Clasen (Luxemburg Minister), the Rt. Hon. Viscount Bruce of Melbourne, P.C., C.H., M.C., the Rt. Hon. Sir Cuthbert Headlam, Bt., P.C., D.S.O., M.P., Admiral Sir John H. D. Cunningham, G.C.B., M.V.O. (First Sea Lord and Chief of the Naval Staff), Vice-Admiral D. C. Ford, C.B.E. (Engineer-in-Chief of the Fleet), Lt.-Gen. Sir Frank E. W. Simpson, C.B., D.S.O. (Vice-Chief of the General Staff), Sir John Lennard-Jones, F.R.S. (Chairman, Ministry of Supply Advisory Council on Scientific Research), Lord Hyndley, G.B.E. (Chairman, National Coal Board), Mr. L. O'Connor (Director of Carbonisation, National Coal Board), Mr. A. W. Stevens (Prime Warden, The Worshipful Company of Blacksmiths), M. Leo Clasen (Industrial Adviser to the Luxemburg Government), M. Aloyse Meyer (Luxemburg), M. F. Paul List (representing the Association Luxembourgeoise des Ingénieurs), Dr. E. L. Dupuy (representing the Société Française de Métallurgie), Mr. W. Friedhoff (representing the Koninklyk Instituut van Ingenieure), Mr. B. Müller (President, Norsk Metallurgisk Selskap), Professor Dr. R. Durrer (Switzerland), Mr. R. Quijano, Mr. S. Fornander, Sir Clive Baillieu, K.B.E., C.M.G., Sir W. Benton Jones, Bt., Sir William Griffiths, D.Sc., Sir Hugh Bell, Bt., and the Presidents of many kindred Societies.

The Toast of "The Iron and Steel Institute and Industries" was proposed by the Rt. Hon. Lord Cherwell of Oxford, P.C., F.R.S. The President, Dr. C. H. Desch, F.R.S., replied and went on to propose the Toast of "The Guests." To this the Rt. Hon. W. J. Jordan, High Commissioner for New Zealand, replied.

Presentation of Papers

The following papers were presented and discussed:

Thursday, 15th May:

Morning Session

"A New Scheme for the Microchemical Analysis of Ferrous Alloys," by E. J. Vaughan and C. Whalley.

"Graphite Formation in Cast Irons and in Nickel–Carbon and Cobalt–Carbon Alloys," by H. Morrogh and W. J. Williams, *and*

"A Note of the Mode of Occurrence of Tellurium in Cast Iron," by H. Morrogh. (*Joint discussion.*)

"A Photographic Investigation of the Brightness Temperatures of Liquid Steel Streams," by J. A. Hall, *and*

"A Symposium on the Contamination of Platinum Thermocouples," by the Liquid-Steel Temperature Sub-Committee of the Alloy Steels Committee of the British Iron and Steel Research Association. (*Joint discussion.*)

Afternoon Session

"The Operation of Open-Hearth Furnaces with Coke-Oven Gas," by D. Kilby, *and*

"An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems," by A. H. Leckie, J. F. Allen, G. Fenton, J. R. Hall, and C. Cartlidge. (*Joint discussion.*)

"Application of Slag Control and an Investigation of Basic Open-Hearth Furnace Slags," by T. Fairley, *and*

"The Effect of Temperature on the Phosphorus Reaction in the Basic Steelmaking Process," by K. Balajiva and P. Vajragupta. (*Joint discussion.*)

Friday, 16th May:

Morning Session

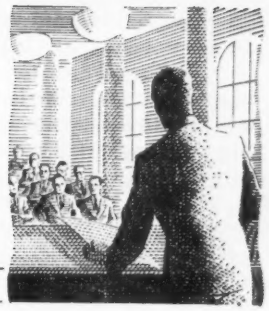
"First Report of the Rolling-Mill Research Sub-Committee of the Iron and Steel Industrial Research Council" (Special Report No. 34),

"Fluctuations of the Distribution of Torque between Rolling-Mill Spindles," by E. A. W. Hoff, *and*

"The Application to Shaping Processes of Hencky's Laws of Equilibrium," by E. Siebel. (*Joint Discussion.*)

The discussions on these papers are printed in the following Section, pp. 487–522.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Spring Meeting, 1947

Discussion on the Paper—
A NEW SCHEME FOR THE MICROCHEMICAL ANALYSIS OF FERROUS ALLOYS,*

By E. J. Vaughan and C. Whalley

Mr. **Vaughan,** in presenting the paper, said that there was an error in Fig. 16 (*c*). This diagram should refer to chromium, and not to nickel, as now printed.

DISCUSSION

The **President** (Dr. C. H. Desch, F.R.S.) : These microchemical methods for the analysis of alloys are extremely beautiful, and give a very high degree of accuracy. It is gratifying to know that the principal progress has been made in this country by British workers, and that the instruments used are essentially of British manufacture, so that the spectrographs devised for this work are exported to other countries in which the method has been taken up. The development of these methods has been very largely due to Mr. Vaughan and his colleagues, and their paper is a very welcome one.

Mr. **G. E. Speight** (The United Steel Companies, Ltd., Stocksbridge, Nr. Sheffield) : I should like to congratulate the authors on the neat and orderly manner in which they have set out the results of their work. This paper is a really fine effort. It occupies some twenty-eight pages of the *Journal*, but in spite of its length it is very readable. Those members who are chemists will have read it and will constantly refer to it in the future. To those who are not chemists, I can heartily commend the paper as being an interesting account of some really painstaking work.

The authors have been successful in applying one of the latest tools of analytical chemistry, to micro methods, and this is particularly important, because it would now seem that we have available microchemical methods for analysis which do not require any really special apparatus or technique, and which should be well within the scope of the average skilled analyst.

Although we have these new methods, we must still maintain a sense of proportion, because they do not in any way compete with the normal macro methods. Each of the two, the micro and the macro, has its own fields of application, and some of the fields of application of the micro technique have been very clearly defined in the paper. The main benefit of these microchemical methods is that they give us a new tool, an alternative means of dealing with certain special problems.

There is very little in the paper which can be criticized. The paper is completely factual, and is merely an account of how two workers solved a certain problem. No doubt other workers would have achieved a successful solution, in which certain of the methods recommended would have differed from those recommended by the authors, but such differences will always exist so long as we have chemists and metallurgists.

**Journal of the Iron and Steel Institute*, 1947, vol. 155, April, pp. 535–562.

To give the authors something to bite on, there are a few points which I should like to mention. First, with regard to the preparation of the samples, we are told that they have to be milled or drilled to a very fine state of division, and then they are magnetted or hand-picked to free them from impurities. What is the actual extent of the impurities ? Has that been measured ? I should like to suggest that some alternative method of obtaining the samples, such as milling or drilling under paraffin or some other liquid, might serve to cut down the extent of contamination.

Secondly, on the question of carbon determination, I think that we all appreciate the reason for the treatment of the absorption bulb, where it is damped and dried with a chamois leather cloth, but has that any advantages over the standard practice using a microchemical balance ? Furthermore, in a dust-free and fume-free room, it should be possible to obtain results of equal accuracy without complicated methods of wiping, rubbing, or polishing the absorption bulb.

Finally, with regard to carbon determination, I think that the advantages of an all-dry purification and absorption train should merit very serious consideration.

Mr. **G. Murfitt** (Messrs. Wm. Jessop & Sons, Ltd.) : I wish to add my congratulations to those already offered to the authors. Like previous work from the Bragg Laboratory, this work is very detailed and comprehensive. The authors set out with the avowed intention of making use of absorptiometric methods wherever possible, and they have succeeded in doing this for all the elements listed with the exception of carbon. Many people use the absorptiometer today, but very few realize what a small weight of sample is actually involved in the final measurement. About ten years ago we were using the Pulfrich photometer in the determination of molybdenum. On the macro scale one takes a sample weight of 0·5 g., but the solution is so diluted in the process of analysis that the actual measurement, even in a 5-cm. cell, is made on about 7 mg. The authors have seized on this and, using the micro-balance, micro-apparatus, and micro-cells, they have produced methods which the average analyst can use successfully after a short period of training in the special technique.

Whilst the methods given in the paper were developed for certain particularly small samples, one looks forward to the possibility of using these, or similar methods, in routine works' analysis. Before this can be realized it will be necessary to find out whether it is possible to set up and operate a micro-balance in the works laboratory. Vibration arises from various sources, and a special laboratory may have to be built or at least a special stand for the balance. The preparation of samples is most important, and unless this is carefully carried out the analysis will be worthless. This should have been emphasized in the relevant paragraph on p. 538.

Have the authors any evidence that the effects of segregation are no greater in micro than in macro analysis ? A 4-mg. sample for manganese, or a 10-mg. sample for sulphur, seems to be very small but, of course, the effects of segregation can be minimized by taking a larger initial sample weight and fractionating this, as in the composite schemes.

The saving in reagents is very attractive, but the authors do not mention the saving in time except to say that the complete analysis of B.C.S. ' W2 ' can be completed in 14 hr. If space could have been found to give the approximate time required for each method of analysis it would have enhanced this very valuable paper, which will be a work of reference for all who are interested in the analysis of ferrous alloys.

Mr. **B. Bagshawe** (The Brown-Firth Research Laboratories, Sheffield) : I should like to congratulate the authors on a most notable contribution to the progress of microchemistry. I feel there is little doubt that the application of technique and principles which they have made will be the foundation of ferrous micro-analytical practice as we shall know it for some years to come. There will be changes and improvements based on subsequent experience, but these will largely be natural developments arising from and stimulated and accelerated by the influence of this paper.

It is easy to be critical if one wants to be so, but the general level of the paper is such that criticism is almost necessarily restricted to points of detail. I think that the general approach and treatment which the authors have applied is above criticism.

The purist might like to see more use made of classical analytical procedure, and it would be interesting if we could have the opinion of the authors on the potential value, on the micro scale, of such elegant procedures as, for instance, the ether separation, the mercury cathode separation, cupferron precipitation reactions, etc. I feel that some of these separations, at any rate, may function more satisfactorily on the micro scale than they do in established macro practice, and that there may be applications for them in the micro field which are not readily workable in full-scale practice.

I note that the authors have not covered aluminium, and I feel that this is an important omission, not only from the point of view of determining the aluminium content of steel, but

because it is a very necessary requirement if we are going to make full use of micro-analytical technique in the analysis of non-metallic inclusions.

I cannot place much reliance on iron determinations by the ammoniacal citrate colour, put forward by the authors, and this, in my view, is the weakest test in the whole paper. There is a Table early in the paper, which indicates a range of 0 to 100% of iron for a 2-mg. sample, but later, when the authors give the calibration curves and discuss scope and accuracy, there is a statement to the effect that a range of only 0 to 6% of iron is covered by the 1-cm. cell. Does not that mean that we can only go up to 24% of iron if we use the 0·25-cm. cell, the smallest cell in the whole series ?

I cannot see the point of giving two methods for the purpose of covering chromium in the range 0–6%. Our experience of the separation method is that the separation by caustic soda leads to absorption losses of chromium, and there may be a danger of chromium reduction by residual undecomposed peroxide. We have the authors' evidence that the direct method gives a better accuracy range than the separation method, so why retain and include the separation method ?

For larger amounts of chromium, *e.g.*, as in stainless steels, would not it be better to adopt microtitration technique instead of the absorptiometric evaluation of the rather insensitive dichromate colour; or alternatively, since the authors use diphenylcarbazide in the low chromium ranges, cannot they utilize it equally well in the high chromium ranges, merely by suitable dilution of the final volume ?

With regard to sulphur, I think that it would be of some interest if the authors could indicate to us the percentage yield of sulphur to be expected on the micro scale. There are certain differences on the micro scale. I think that the fixed tube temperature would be more uniform, as there is less boat chill and less heat of reaction. The authors' experience might possibly help in pointing to a better understanding of the reasons for the non-stoichiometric nature of this reaction.

I note that throughout the paper they have made a point of giving the degree of accuracy which can be expected for various determinations, but I do not think that they give us any idea of the accuracy to be expected from the carbon determination, and I wonder what sort of accuracy we can expect in carbon determinations on 18/8 austenitic steels of the 0·05%-carbon class.

I think that a general query might be raised about the rather frequent use of correction factors. It can become complicated, and I think that there is a certain loss of elegance in the additive effect of corrections for so much of chromium, so much of nickel, so much of cobalt, and so on, particularly where these occur together in one determination. I should like to know what the authors think of the alternative procedure of compensating by dividing the solution, as is often done in macro practice, and using two solutions, one reagent-treated and one not. Would not the accuracy be improved in that way ?

We may be able to look forward to an accelerated rate of development of microchemistry as applied to our problems, as the result of this paper.

Dr. **Brynmor Jones** (Whitehead Iron and Steel Co., Ltd., Newport, Mon.): I wish to put on record how much the steelworks' chemists appreciate the absorptiometric methods evolved by Mr. Vaughan in the past. This paper deals with the determination of fairly appreciable amounts of various elements in steel, and as the analyses are carried out on very small weights of sample, in this respect the scope and accuracy of the methods are large. The very small weight of the sample and volume of the reagent, call for a special technique. The instructions on p. 543, for example, to dissolve 0·4 mg. of sample in 0·5 ml. of 5% Spekker acid, will make all steelworks' chemists sit up and take notice of the accuracy that can be obtained with these small weights.

I note that the average deviation from the mean figure for nickel in steel is $\pm$ 0·05% in the range 0·0–4·0%. This means that the determination of small amounts of nickel in steel, which is often required in testing for residual elements, is ruled out. I remember many years ago, when carrying out work on the heterogeneity of steel ingots, that for ingots containing less than 0·1% of nickel, the current methods for the determination of nickel were most inaccurate, and I had to evolve a colorimetric method that gave accurate results down to 0·001%, based on the colour given by the oxidized dimethylglyoxime complex referred to in the paper.

Again, the determination of carbon in low carbon steels is important, as well as in ingot iron, electrolytic iron, etc. As an interesting case, I would mention the fact that some years ago, when carrying out some work on pure irons, I passed a sample of N.P.L. pure iron to some very reputable steelworks' chemists for the determination of carbon. The iron was stated to contain less than 0·001% of carbon. The figures reported to me were 0·030–0·045% of carbon, which makes one feel very suspicious about the results given in the low carbon range of steels. I would suggest that perhaps a microchemical finish for carbon, by combustion, could be carried out by using a large weight of sample for low carbon steels.

AUTHOR'S REPLY

Mr. **C. Whalley** (Bragg Laboratory, Naval Ordnance Inspection Department, Sheffield), in reply, said : We meant this paper in the first place to be in the nature of a start on the subject. I know quite well that since these methods were submitted, many workers have followed on, and have perhaps even now, progressed a good deal further on than some of these methods indicate. At the time that these methods were submitted and when the paper was written, which is over twelve months ago, we did not know some of the more advanced applications of which other people have since told me. They have indicated that we might have benefited if we had followed certain lines of development.

With regard to the specific points which have been raised, Mr. Speight referred to the technique which we applied for wiping the carbon tubes before weighing them on the microbalance. I think that the paper cannot be quite clear there, because we do not adopt the wiping technique at all. As is said in the paper, we first wipe the tube before we start. That is necessary, because it may have stood for some time and may have a dust film on it ; but once we have wiped it we do not adhere to any specialized technique of wiping after that ; we simply wear gloves when handling the tubes, so as not to allow perspiration from our hands to get on the tubes. As a result, we found it unnecessary to take these rather complicated precautions which the organic micro-analysts put forward. That is one point which is worth mentioning, because it is being applied now to the organic field as well as to the inorganic.

The use of an all-dry train for carbon has its advantages, but personally I prefer the chromic acid bubbler tube, because it gave us an indication of how the combustion was proceeding and whether there was a sufficient supply of oxygen passing through the train. That is very important, because if you do not get a sufficient supply of oxygen—we are not using any flux—there is a danger that some of the carbon may not be fully converted to carbon dioxide and may pass through the train. An adequate supply of oxygen is necessary, and the bubble counter, which is put after the combustion tube, acts as an indicator as to whether the oxygen supply is adequate.

The accuracy of the carbon determination is not given in the paper. It depends very much upon a variety of circumstances. If you have a 50-mg. sample of steel and if it contains 1% of carbon, you get only about 1·7 mg. of carbon dioxide, and 1·7 mg. is not very much to weigh even on an accurate microbalance. We found that when working with a sample weight of 50 mg., the accuracy which we normally obtained over a normal range of steels from 0·1% up to 1% of carbon, was about ± 2%. So far as the very low carbon steels are concerned, we did not profess to be able to determine very low quantities, and we never had to contend with quantities of the order of 0·001% ; but I do see that it is quite possible that the microchemical finish could be applied to the macro tube, thereby starting on a sample weight of 2 or 3 g., and getting perhaps 1 or 2 mg. of carbon dioxide from that sample, absorbing it in the micro absorption train and weighing it on the microbalance. That is a distinct possibility.

With regard to criticisms of the methods in general, we have tried many of the suggestions which have been put to us. I have done a good deal of work on some of the separations which we have been asked whether we have tried, and we found that if we could do without them we preferred to do so. We do not particularly condemn them. We found that we could use the ether separation and the cupferron precipitation for some of these methods if we wanted to, but we found it unnecessary to do so if we could produce satisfactory colour complexes without doing any cupferron separation at all.

In the paper, we refer briefly to possible measures for zinc and lead. The method for lead which we had in mind we have not put in the paper, because it was not complete. It involved the use of ether separation. We have done a little work on cupferron separations, but not precipitations, where the actual cupferron complex is dissolved out of the solution by an organic solvent, which, in our opinion, is a better way of carrying out some of these separations, than getting a huge precipitate and then having to filter it off. That is a line which I consider well worth pursuing, and which might yield quite profitable results with certain of the methods.

We did not include aluminium, because I must admit that we had not found a method which is completely satisfactory. We have tried all sorts of ideas which have appeared in the literature, but we have not yet found a method which would produce results of sufficient accuracy to merit its inclusion in this paper. We did not want to put into the paper tentative methods, but only methods which we had tried and which we thought that other people would be able to apply without a great deal of trouble. That is one of our reasons for including, in some cases, more than one method. In the particular case of chromium, two methods were given for the analysis of alloys of up to 6% concentration, but that was because we thought they were of sufficient interest to merit putting them both in. If you read the composite scheme of analysis, you will see that we invariably plump for one

particular chromium method. The other was put in so that people could get an idea of the type and variety of methods which we had investigated.

The idea of some of this work is one which I should like to put forward now. We are working on very small amounts of material, and we were asked what the effect would be if we were dealing with 80-ton ingots. That is a question which I should like to leave my co-author to answer. I should like to suggest, however, the possibility of working on a semi-micro scale on sample weights of the order of perhaps 100 mg. Our methods could be readily stepped up from these micro-methods to give us a similar scheme of analysis which would be more readily applicable to ordinary steelworks' laboratory practice, and I think that is a point which might well be borne in mind. We did not develop these methods to substitute them for full-scale routine analysis ; we developed them, as we have said, for a special purpose ; but, having developed them, the implication as to what might happen if we took slightly larger weights of sample should, I think, be apparent, and should give rise to the possibility of a modified scheme which could be worked in an ordinary laboratory, without even the necessity for having a micro-balance or small microchemical glassware.

Joint Discussion on the Papers—

GRAPHITE FORMATION IN CAST IRON AND IN NICKEL–CARBON AND COBALT–CARBON ALLOYS* *by H. Morrogh and W. J. Williams*

and — A NOTE ON THE OCCURRENCE OF TELLURIUM IN CAST IRON† *by H. Morrogh*

Mr. **H. Morrogh** (British Cast Iron Research Association, Birmingham), who presented both papers, pointed out that in the second, which was printed in the *Journal* for January, 1947, on page 22, in the last paragraph of the second column, the first reference to Figure 5 should read " Figure 6 " and the second " Figure 6 (*a*)," while on page 23, in the second paragraph, in the eighth line, Figure 6 should be " Figure 5."

DISCUSSION

Dr. **J. E. Hurst** (Messrs. Bradley and Foster, Darlaston, Staffs.) : It is a very great privilege to have the opportunity of opening the discussion on what I regard as a masterly effort by the authors. I do not think that the synopsis of the first of these papers, or the paper itself, do full justice to the enormous amount of work which has been done by Mr. Morrogh and his associates at the British Cast Iron Research Association. Although the paper is a long one, it does not convey in the slightest an impression of the hundreds of experiments which have been performed by Mr. Morrogh in particular, assisted by the staff of the Association.

I should like to congratulate Mr. Morrogh on the presentation to him this morning of the Carnegie Gold Medal. We who are connected with the Research Association are very pleased to find that his work has been recognized in this manner. I understand that in making the presentation the President referred to his marvellous work in developing the methods of examination of the graphite phase, which is the most important phase in the alloy with which we have to deal.

I suggest that Mr. Morrogh is the first man ever to see graphite in cast iron under the microscope. For many years we had been in the habit of regarding black streaks in our microphotographs as graphite. Mr. Morrogh's work has shown us that many of these were nothing but holes, and the true form of the graphite can be clearly revealed by the use of a polishing technique that he has developed. This work alone has increased our knowledge very considerably, and it has enabled him to identify the carbon phases resulting from annealing with that which results in ordinary solidification. In this connection his investigation of the spherulitic form is of very great importance.

The authors have not told us in this paper all they know about the formation of graphite. The knowledge of the subsequent and additional work of the authors to that described in the paper makes it difficult to be critical, for the very simple reason that the results derived from this work have turned out to be of very great industrial importance. As announced by the President of the British Cast Iron Research Association at the annual meeting of that Association, the results are likely to revolutionize our cast-iron industry. Mr. Morrogh has been able to take this work so far as to be able to control the form of graphite in cast iron under ordinary conditions of solidification and, within limits, to produce these spherulitic structures more or less at will and obtain the properties in the resulting material associated with graphite in that form. That is a very valuable

**Journal of the Iron and Steel Institute*, 1947, vol. 155, Mar., pp. 322–371.

†*Ibid.*, 1947, vol. 155, Jan., pp. 21–23.

discovery to have made, and it arises from the work which has been going on continuously in the British Cast Iron Research Association.

I as an individual am not completely satisfied that the authors have shown that what they call flake graphite does not originate *via* a carbide phase in its formation. I am very pleased to see that they have confirmed the work of Eash, and have shown that what he calls supercooled graphite originates *via* a carbide phase. I hope that it will be possible to continue this work still further, and that we shall have a much clearer understanding than I have from this paper as to how flake graphite originates.

What causes me difficulty is Fig. 121. I do not know whether the authors regard all the graphite disclosed in that Figure as undercooled graphite, but it looks to me as if in addition to undercooled graphite there is some flake graphite there. In the work in my laboratory we come across many examples of this type of occurrence, where we have the simultaneous presence of undercooled graphite and flake graphite in close proximity, and it causes us some difficulty in trying to understand how one can originate in one manner and the other in another manner within such a small space.

I am naturally particularly interested in the work which the authors have done on the formation of undercooled graphite in high-silicon irons. That is a subject which has been studied very intensely in my own laboratory, and it is because of the results of that study, which is hardly yet completed, that we have these difficulties in understanding the origin of flake graphite. We take the view, which we have already recorded in a previous paper here, that carbide, or a carbide-looking phase, does exist in high-silicon iron alloys, that is, in alloys containing up to 14–18% of silicon. On quick cooling in the commercial varieties of the alloys—and it is important to emphasize that, because in the commercial alloys there are all sorts of impurities (manganese, sulphur, phosphorus, and so on)—we invariably produce a carbide-looking phase, but we are satisfied in our laboratory that that carbide-looking phase is not the simple carbide, Fe_3C. Its carbon content is substantially different. That we can determine. Furthermore, we are virtually satisfied that that carbide-looking phase also contains silicon, and we are almost satisfied that it contains as much silicon as there is in the matrix, because on heat-treating a 15% silicon alloy containing that carbide phase the decomposition products are graphite and a ferrite phase. The ferrite phase seems equally corrosion-resistant to the main bulk of the ferrite phase, which depends for its corrosion resistance on its silicon content. The conclusion seems irresistible that the ferrite which results from the decomposition of the carbide phase in a high-silicon alloy contains at least enough silicon to make it corrosion resistant. We feel, therefore, that the original carbide phase must have had that silicon in it.

Whether that silicon is responsible for the carbon content I do not know, but it leads to the conclusion that the carbide phase in the high-silicon alloys may be a different carbide phase from that which exists in the ordinary grey irons with which we have to deal. In one or two places in the paper the authors refer to the form of the carbide or the cementite, and I strongly suspect that they found that perhaps there are different forms of carbide phases even in ordinary grey irons.

We in our laboratory hardly appreciate why Mr. Morrogh felt it necessary to add 0·47% of titanium to this 10% silicon iron to preserve the undercooled graphite. Our experience is that titanium does not always do that, at any rate. We are aware of a common commercial variety of acid-resisting silicon iron which contains 0·35% to 0·5% of titanium, and it is as beautiful an example of flake graphite material as can be desired. I mention that point because it serves to indicate that in this particular alloy which Mr. Morrogh was examining there are other things than silicon.

On page 331, in the second paragraph of the second column, reference is made to the soundness of castings associated with the undercooled graphite structure. That is also something which interests my laboratory, and we have done some work in that field. We confirm the authors' findings, but we would go a step further. We have been investigating the gas content of cast irons, and we take the view that, at least as far as centrifugal castings made in metal moulds are concerned, the gas content or the absence of gas content is a factor which cannot be neglected in considering the soundness of castings produced by that method. Of all the samples which we have examined, the lowest hydrogen content in any cast iron we have examined so far was found in the centrifugal castings. Whether that is due to the centrifugal casting method alone, or to the use of the metal mould, or to both, it is too early yet to say, but I want to emphasize that in our opinion the gas content, and particularly the lower hydrogen content, in metal-mould castings of that type must not be neglected in attempting to understand why such castings are generally sounder than others.

These few remarks are in the nature of comments, and in my opinion the paper as a whole will be of inestimable value for years to come, and in fact may rank as a classic of this subject.

Mr. **J. G. Pearce** (Director, British Cast Iron Research Association, Birmingham) : As the Cast Iron Research Association made an announcement towards the end of 1946 with respect to the production of cast irons containing nodular graphite structures, I think it proper to say that, whilst the paper now under discussion deals with the theoretical background and the approach which preceded this development, the paper itself was prepared before this actually took place, so that the development must remain the subject of a future communication.

With reference to the procedure referred to as inoculation, I believe that in the Cast Iron Research Association we began to use that term for the first time about 1929. It was intended to imply the very marked affect resulting from a very small cause, that is, ensuring that a melt of cast iron which was such as would solidify as white iron, could be made completely grey by a small ladle addition of the order of 1 part in 400. The widespread adoption of this term in this country and in the U.S.A. suggests that it serves a useful purpose.

With reference to the ferrite-fine graphite structure, the undercooled graphite structure, before the war, with the co-operation of the late Dr. T. Swinden, an attempt was made to see whether this structure would serve in the form of cupola-melted ingot-mould material, using the titanium/carbon-dioxide process, which was the only positive method we knew at the time which would produce the structure. That, as this paper shows, is not now the case, but moulds treated to produce the structure gave a life of only 10% more than the untreated metal, and that was not regarded as enough to justify the time taken by the treatment.

While we appreciated at that time that hydrogen would cause the molten metal to revert to the flake graphite structure, we did not appreciate that in cupola melting the metal could pick up enough hydrogen from the moisture in the sand bed and from a not completely dried-out refractory lining to mar the success of the experiment. However, we also now know that that structure is probably too rigid for ingot-mould purposes, except for those which would fail exclusively by crazing.

Mr. **M. M. Hallett** (Sheepbridge Stokes Centrifugal Castings Co., Ltd., Chesterfield) : The subject matter of this paper is of fundamental importance to the well-being and future progress of the industry, and I can think of no higher praise than to say that the paper is worthy of its subject. I do not want to make any comments on the main lines of reasoning or the conclusions reached, but shall confine my discussion to one or two small points.

The authors consider the early work of Miers and Isaac on undercooling in the betol–salol system and attempt to apply the conclusions to cast iron, quoting some structures obtained by Nipper as examples of undercooling in cast iron. The structure shown in Fig. A could be taken as an example of the same type of process, apparently showing primary austenitic dendrites crossing primary carbon plates. Unfortunately the history of the sample is obscure. "Hard spots" showing the structure were observed during the machining of a centrifugally cast grey iron containing 3·3% of carbon, 2·4% of silicon, 0·6% of phosphorus, and 0·35% of chromium. The inclusions probably represent phosphide exudations into blow-holes.

The authors advance two possible theories to explain the structures found by Nipper, namely undercooling and absorption of the graphite from the eutectic by the primary kish, and they cite the absorption of austenite from the white-iron eutectic by primary austenite dendrites as a

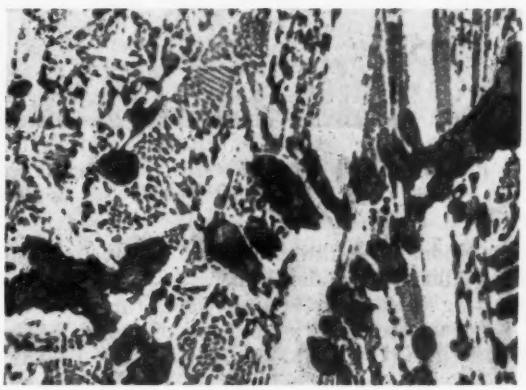


FIG. A—Structure of inclusion in centrifugally cast grey iron (B.S.S. 4*K*6). ×650

parallel case. In my experience the structures of the white-iron eutectic depend on the speed of cooling and the total carbon content, amongst other factors. At ultra-rapid rates of cooling, the structure is invariably duplex and fine, but at more normal rates the shorter the distance that the austenite component of the eutectic has to travel in order to reach the primary dendrites (that is, the lower the total carbon content), the more complete is the separation. The slow speed of Nipper's cooling thus suggests the agglomeration of graphite on to the primary kish as the probable reason in his case, though it must be confessed that the austenite envelope shown in Fig. 22 has a remarkably dendritic appearance.

There is one other feature of the white-iron eutectic which I have not been able to explain satisfactorily, namely, the acicular character it

sometimes assumes, illustrated in Figs. 66 and 124. It seems to be connected to some extent with the thermal gradients existing at the time of solidification, but that is not a complete explanation. I am very interested in the authors' suggestion that the structure may be due to the undercooling of the white-iron eutectic, though I do not think that the evidence in the paper is sufficient to prove this. Perhaps the authors have carried out additional experimental work. Certainly the acicular eutectic can be formed in conditions which would seem to preclude any possibility of undercooling, as in centrifugal casting when there is appreciable turbulence.

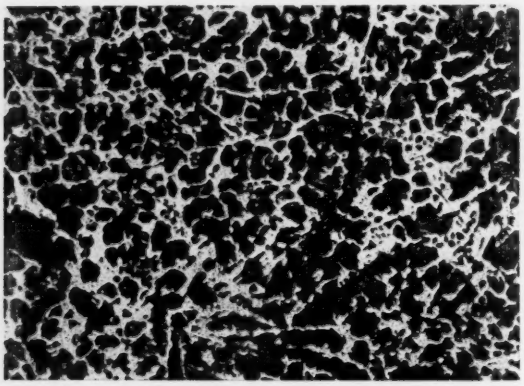


FIG. B—Deep-etched form of carbide eutectic in centrifugally cast white iron (D.T.D. 485). ×96

A deep-etched structure of a centrifugally cast white iron (D.T.D.485) is shown in Fig. B, which illustrates the normal sort of eutectic, though there are obviously some needles. That the structure can acquire a decidedly acicular character for no very obvious change in conditions is shown in Fig. C.

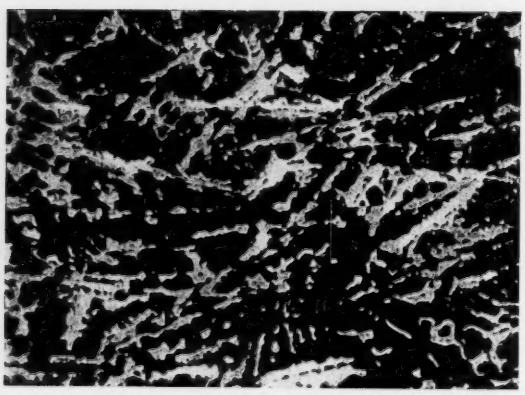


FIG. C—Deep-etched acicular form of carbide in centrifugally cast white iron (D.T.D. 485). ×96

I am very glad to note the authors' criticism of the theory of the formation of ferrite by the breakdown of cementite at high temperatures, as suggested by Piwowarsky. It is surprising that that theory was ever put forward. I am studying the formation of ferrite in cast irons, and so far as my tests have gone they entirely confirm the authors' finding that ferrite is formed only at lower temperatures near the critical range. Conversely, on reheating an entirely ferritic grey iron, the graphite flakes rapidly redissolve to form a high-carbon austenite, so that the sample can be hardened effectively on quenching.

Finally, I regret the continued use of the term "silicate slime" in describing the theory of von Keil, Mitsche, Legat, and Trenkler. The word used by them was "Silikattrübe," trübe meaning cloudiness or turbidity. One can form a cloud by a suspension of solid particles, whereas the word "slime" has a definite liquid implication. That they were talking about solid particles is clear from a study of the paper and from the later writings of Mitsche in the Carnegie Scholarship Memoirs of this Institute for 1934 and 1936. The translator of those memoirs used what I think is the correct translation, "silicate cloud." The use of the term "slime" tends to make the similarity between the theory of von Keil and that of Norbury and Morgan much more close than is actually the case, and does less than justice to the originality of the viewpoint of Norbury and Morgan.

Dr. **E. M. Trent** (Hard Metal Tools, Ltd., Coventry): I should like to congratulate the authors and to emphasize the fact that this paper is not only of practical significance but also of great theoretical significance, and that the points of theoretical significance will have wider scope than the applications to cast iron. I am particularly interested in the cemented carbides, and I think that this paper may have some application to them. They consist largely (80 to 90%) of carbides, either tungsten carbide or a mixture of tungsten and titanium carbide, the other 10 to 20% being any one of the three elements of the iron group. In commercial alloys it is mostly cobalt, but it can also be either nickel or iron. If the carbon is sufficient to saturate the normal carbides present, only two phases are present, as a general rule, but if it is more than sufficient for this the carbon is precipitated in the form of graphite, and in each case the graphite takes up a similar formation, namely, small clusters or aggregates of randomly oriented flakes of graphite.

Even in the case of carbides bonded with iron

I have not been able myself to identify any cementite. In these alloys the iron or the element of the iron group in the liquid phase is in contact over a very great area with another phase which may act as almost a perfect inoculant. I think some information of interest on the mode of occurrence of carbon in alloys containing iron, nickel, and cobalt can be obtained from the study of these materials.

In only one case have I found a phase which may have been either nickel or cobalt carbide, and I shall be grateful if the authors can supply some metallographic evidence which could be used to identify the nickel and cobalt carbides, such as etching characteristics, etc.

Mr. **E. Morgan** (Stanton Ironworks Co. Ltd., Notts) : It gives me great pleasure to take part in the discussion on this remarkable paper. Having spent many years myself trying to solve some of these problems, I can say unhesitatingly that in my opinion this is the best paper ever presented on this subject in this or any other country.

The scope of the paper is very wide, and it is difficult, as Dr. Hurst has said, to pick out any specific part for discussion. I would divide the paper into two parts. There is, first of all, the part which deals with the large number of anomalies in cast-iron metallurgy, and which gives a very clear statement of the problems involved. In the second part, the authors describe their own experimental work, the results of which have thrown so much more light on the subject. In this connection the experiments on the nickel–carbon alloys are extremely interesting.

I should also like to say something about the wonderful series of photomicrographs of cast irons and graphite flakes shown in this paper. We hear a good deal these days about the time being ripe for applying the technique of X-ray diffraction to the study of problems of cast iron, but I think that there is still a great deal that the metallurgical microscope can show us when handled in the way in which these two authors have handled it. They get hold of a graphite flake, so to speak, and turn it this way and that, until they are satisfied that it is graphite and nothing else. Not only can they say that it is graphite, but they can tell us precisely what form of graphite it is, and they go further and say that this graphite has been formed in a particular way.

I have only one real criticism of this paper, and that is with reference to the work of Eash on the formation of supercooled graphite. I think that the present authors are far too modest when they say that they have merely confirmed the findings of Eash. That investigator carried out his work on a very large test-bar, 6 in. long and 1·2 in. in dia., cast in a sand mould, and he claimed that he was able to control the quenching temperatures and so forth on such a large bar. He also picked out a very abnormal composition, namely, a very low-carbon iron, which one would regard as having a very strong chilling tendency, and I feel that he tended to generalize too far on the results obtained from experiments which were limited in their scope. On the other hand, these authors have used many different compositions ; they have used a much more precise experimental method, and they have been able to show that " supercooled " or " undercooled " graphite does actually form as a decomposition product of white iron. Although hitherto I had regarded supercooled graphite as forming directly from the melt, I accept the findings of the authors without any reservations at all.

There are one or two other items on which I should like to say a word. My first point is with reference to the refining action of titanium and zirconium. The authors say that the refining action is related to the formation of carbides of these elements. I do not think that that is quite correct. One would agree that when sulphides of these elements are formed, the structure is a coarse graphite structure, but I should like to ask the authors in what form they find the zirconium or titanium when a melt containing one of these elements has been treated with hydrogen in order to coarsen the graphite.

I should like to hear more from them about the actual function of calcium silicide as an inoculant. I recall that in the early part of the war the British Cast Iron Research Association tried to discover a substitute inoculant for calcium silicide when supplies threatened to become scarce. We never actually discovered anything quite so good ; the nearest was an alloy containing 30% of aluminium and 70% of silicon. Perhaps the authors can give me a little more information on that point.

With regard to the function of carbon and silicon in the inoculation process, the now-established fact that supercooled graphite is a decomposition product of white iron makes it clear why the introduction of free graphite to a melt, or graphite precipitated from a melt by an addition of ferrosilicon, is not an efficient means of preventing the formation of supercooled graphite and forming normal flake graphite. On the other hand, graphite or ferrosilicon additions would be expected to coarsen the graphite structure where supercooling is absent, and refinement is the consequence of a rapid rate of cooling or of a low-silicon and/or low-carbon content.

Another point is with reference to the possible effect of manganese sulphide as an inoculant under certain circumstances. Some time ago I came

across a reference in Mellor's text-book on inorganic chemistry to the effect that manganese sulphide can dissolve carbon at high temperatures and precipitate it as graphite on cooling. Have the authors come across any evidence of this ?

With regard to the suggestion that the deoxidizing influence of small aluminium additions is connected with the graphitizing power of this element, Norbury and I, some years ago, carried out experiments in the course of which we added 0·1% of aluminium to Swedish white-iron melts. These were only 100-g. melts, and we found that if we just stirred in the aluminium addition and immediately withdrew the crucible and allowed it to cool, the structure was completely grey ; if on the other hand the melt, after the aluminium addition, was allowed to stew for a few minutes before being taken out, a thick blanket of aluminium oxide formed on the surface of the melt and the ingot reverted to its original white condition. This effect could be accelerated by passing CO_2 through the melt.

AUTHOR'S REPLY

Mr. **H. Morrogh** (in reply) : I should like to thank those who have contributed to the discussion for their very kind remarks about this work. On the point which Dr. Hurst raised about the formation of carbides in silicon alloys, I noticed that he was very careful to say " a carbide-looking phase." There is no doubt that two phases are formed. If you take an alloy with anything over about 2·7% of silicon and heat-tint it, if it is white, and look at it under the microscope or examine it with the polarizing microscope, you can find two phases in the carbide ; the light phase is the carbide phase containing the silicon, and the dark phase is the normal Fe_3C. The amount of the white phase increases as the silicon content increases, until at 7% the white phase predominates. As far as we have been able to tell, the silicon content of the carbide is generally the same as that of the matrix up to about 7% of silicon, and it seems that the silicon replaces the carbon in that phase.

With regard to the formation of flake graphite from the liquid or from the decomposition of a carbide, we have never been able to prove that flake graphite forms directly from a carbide, and the subject is further complicated if we consider what happens on the hypereutectic side of the diagram where we have kish graphite floating out very rapidly almost as soon as it forms. We have to imagine a very complicated chain of reactions for the formation of hypereutectic graphite if we assume that it results from the decomposition of a carbide. If, however, confronted with the evidence of the formation of hypereutectic graphite, we assume that it forms directly from the liquid as graphite, it becomes very difficult to hold that eutectic flake graphite forms as the result of the decomposition of a carbide.

As for the question about titanium, we should like to point out that the presence of titanium or titanium carbide does not necessarily guarantee that undercooled graphite will be formed, but it is one of the conditions which favours the formation of undercooled graphite.

In reply to the point raised by Dr. Trent, at the moment we have no metallographic methods for differentiating Fe_3C, cobalt carbide, and nickel carbide when they occur in juxtaposition.

On the point raised by Mr. Hallett and illustrated in his micrographs, we are of the opinion that lamellar or acicular carbides such as he showed are not of the same type as those illustrated in the inverse-chill samples in our paper.

Mr. Morgan inquired about the form of titanium carbide in flake graphite irons, and again I would point out that the presence of titanium or titanium carbide only tends to favour the formation of undercooled graphite. If you treat the melt with hydrogen you get coarse graphite, even though titanium carbide is present. Recently I have studied this question more thoroughly, and in extreme cases with drastic undercooling the form of the titanium carbide is different from that when you get flake graphite formed. When you have flake graphite you have ideomorphic characteristic cubes of titanium carbide. With undercooled graphite you have the allotriomorphic form of the titanium carbide. Obviously there is a connection between the forms of the carbide and whether undercooling has occurred or not.

Joint Discussion on the Papers—

A PHOTOGRAPHIC INVESTIGATION OF THE BRIGHTNESS TEMPERATURES OF LIQUID STEEL STREAMS,* *by J. A. Hall,*

and—A SYMPOSIUM ON THE CONTAMINATION OF PLATINUM THERMOCOUPLES,† *by The Liquid Steel Temperature Sub-Committee*

Mr. **J. A. Hall** in presenting his paper, said that in Fig. 26 (*f*) the reference should be to "shot 14," not "shot 4," and the reference to Fig. 40 should be deleted.

Mr. **E. W. Elcock** (English Steel Corporation, Ltd.) introduced the Symposium on the Contamination of Platinum Thermocouples.

DISCUSSION

Dr. **S. A. Main** (Messrs. Hadfields, Ltd.): For the interpretation of complicated frequency curves, such as those obtained by Mr. Hall for his films, it is sometimes helpful to break them down into their component simple distributions. If he has not already tried this expedient I would suggest it might be worth attempting. It can, naturally, best be done by the author himself, and from the original data. Working, however, as best as possible from the figures in the paper, encouraging results are given.

With Fig. 61, three normal frequency distributions are obtained with peaks at 1476° (29), 1504° (57), and 1540° C. (42). The figures in brackets are the heights of the peaks (*see* Fig. A).

If, as seems probable, the peak at 1476° C. is derived from a comparatively small set of areas of clean steel, broad enough to carry the scanning spot, it should represent the true brightness temperature, and it agrees very closely with the reading, 1474° C., of the optical pyrometer.

The more prominent peak at 1540° C., similarly, should represent the true figure for the slaggy areas which are specially in evidence. These figures of 1476° and 1540° C., when assigned emissivity coefficients of 0·4 and 0·65 respectively, agree almost exactly in giving a black-body temperature, for the stream, of 1607° C., in reasonable concordance with the reading, 1620° C., of the immersion couple taken just previously.

The large intermediate component, with a peak at 1504° C., would presumably be derived from the many situations in which, in this instance, the scanning spot found itself bridging clean steel and slag. Close comparison with the forms of Figs. 53 and 54 would hardly be expected, because of the considerable variation in widths of the bands of clean steel and slag.

All this is, of course, in general accord with the author's own interpretation, but it would seem that such analysis, properly done, might help towards obtaining definite information from an otherwise barren curve.

Other forms of the curves appear equally amenable, and Mr. Hall might like to try analyzing them in this way. Figure 52, for example, appears to be of a very similar character, with its three peaks at 1440° (64), 1477° (12), and 1505° C. (4½); the outer peaks again correspond with emissivities of 0·4 and 0·65 for a black-body temperature of the stream, in this case, of 1567° C. The difference, from Fig. 61, is in the relative sizes of the peaks, doubtless owing to the greater area here of clean metal. The peak at the lowest temperature, at 1440° C., is again in close agreement with the reading 1434° C., of the optical pyrometer, though this does not seem to be the case with some of the other curves.

Incidentally, it is rather embarrassing that the emissivity of 0·65, obtained by the author for a first reflection, happens to be similar to that found by G. K. Burgess, for slag. While, therefore, the author gives quite sound and acceptable reasons

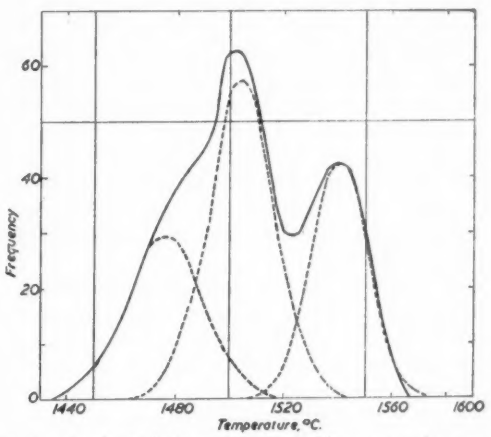


FIG. A—Analytical interpretation of frequency/temperature-distribution curve

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 55–85.

† Ibid, 1947, vol. 155, Feb., pp. 213–234.

for attributing the peak at highest temperature, in Fig. 52, to reflection, may it not also be due in part to slag ?

The many intermediate peaks in some of the curves, *e.g.*, Figs. 56 and 59, constitute a complication. I would suggest they may arise from areas, whether of clean steel or of slag, too small for the scanning spot, but classifiable into groups of varying width, each therefore giving a different and false indication of temperature, either of steel or of slag.

Whether the films will yield definite information or not, by this or any other method, naturally depends on there being enough areas (clean metal, slag, or reflections) of sufficient width for the scanning spot. Whether this is so or not is probably ascertainable during the scanning.

Finally, and as regards Fig. 58, there appears to be rather an anomaly. The peak on the left at 1392° C., is sufficiently high to ensure its indicating the true brightness temperature of the clean steel. This would correspond to a black-body temperature of only 1511° C. for the stream. In view of the satisfactory concordance obtained in other cases, it is clear that the great disparity here from the reading, 1576° C., of the immersion couple, cannot be due to inaccuracies in working ; the physical explanation, when ascertained, should reinforce rather than detract from the value of the work.

I trust Mr. Hall will accept these suggestions in the spirit in which they are made, which is that the research he has conducted has been so cleverly conceived, and represents so much laborious and painstaking work, that it would be a pity if the last ounce of information possible was not obtained from it.

Mr. **D. A. Oliver** (Messrs. William Jessop & Sons, Ltd., Sheffield) : In considering Mr. Hall's paper, I should like to designate it as being in the Schofield tradition. Although I say that, it is also different from the distinctive Schofield contributions, in so far that this work is not being put forward or sponsored with a view to its being turned into a routine, day-to-day method. Some misconception may have arisen on this point, therefore, as ex-Chairman of the late Foundry Steel Temperature Sub-Committee, I should like to explain the general strategy of the work, because I happened to be involved at the inception of the programme.

The quick-immersion method had carried us a long way, and then the point arose of what we were doing, not only for the foundry industry, but also for the ingot-making branch of the steel industry, where invariably the disappearing-filament optical pyrometer was used as a control instrument. It did not take us long to collect criticisms of the available optical pyrometers currently used in British industry. Two lines of work were therefore started ; one was to examine existing deficiencies of optical pyrometers and to set about making a good instrument, and the other was to set about calibrating the radiation upon which the optical pyrometer was sighted, From that angle I cannot over-estimate the importance of this new photographic technique.

Many people know that Mr. Hall is nationally famous as a photographer, both artistically and technically. In this paper he has shown evidence of years of experience, and his recent figure of error of $\pm$ 7° C. is a very great achievement in photographic photometry.

The other important point is that this work is a quantitative study of the fine structure of the radiating streams at the normal temperatures experienced in a steelworks. If we can obtain a good average temperature, we know that in the control of processes we are going a long way, but we are always worried by those occasional readings which are anything up to 30° C. in error. Are we to believe the instrument ? Are we to change the method ? Or are we to have faith in the control ? It is precisely for answering such questions that this programme was undertaken, and is now well advanced and rapidly reaching a point of finality. I believe there is still a certain amount of work to be carried out to round off this research completely, but I would suggest that the work already done is an achievement of the first order. It will stand international examination, and is a fundamental contribution to brightness-temperature measurements. Further, it will give the kind of background imagination needed when we use orthodox optical pyrometers.

I should now like to comment on the rare-metal thermocouple contamination symposium. Some may say that this symposium is making a mountain out of a molehill. However, brittleness in rare-metal thermocouples can be very annoying, and very wasteful economically. If one is tapping a large furnace and there is some doubt about the temperature, owing to the thermocouple wire having broken, the results can be serious indeed.

Learning the lessons of this symposium will go a long way to eliminate such troubles. Finally, I have naturally been gratified to note the contributions of members of my own team, in this valuable collection of papers.

Mr. **Sven Fornander** (Surahammars Bruks A.B., Sweden) : At the Surahammar steelworks in Sweden, some experiments have recently been carried out which seem to show that pyrometer design has an influence upon the contamination of platinum thermocouples. The first series of measurements was made in a small high-frequency induction furnace, and a pyrometer design as

described by Land* was used. This type of pyrometer has a steel chuck mounting to fix the silica sheath in position, and contains no parts that can give off gases when heated. It was found that up to 80 measurements could be made with this type of pyrometer with the same hot junction without any measurable change in the e.m.f. The second series of measurements was made in open-hearth and electric arc furnaces with another type of pyrometer, consisting of an uninsulated steel tube with a graphite end block, and asbestos string for fixing the silica sheath in position. After every tenth measurement with the same hot junction, the pyrometer was calibrated against a standard pyrometer in the high-frequency induction furnace, and was found to read 10° to 20° C. low. This had happened to every hot junction tested.

The end block was then made from steel instead of from graphite, as described by Manterfield and Thurston,† the silica sheaths still being fixed in position by means of asbestos string. After this change in pyrometer construction, the results were rather better, the change in e.m.f. being 8° to 16° (C.) after ten measurements with the same hot junction.

At this stage of the investigation, the asbestos string used for fixing the silica sheath was replaced by steel wool. The result was a success, in so far as up to 50 determinations could be made with the same hot junction without getting any appreciable change in the e.m.f.

The conclusion which we have drawn, from the experiments referred to, is that from a practical point of view it is almost essential that the pyrometer should not contain any parts that are likely to give off gases when heated.

Finally, I should like to express the appreciation which we feel in Sweden for the Schofield-Grace invention for measuring liquid-steel temperatures. We feel that this method has filled one of the most urgent needs in steel-making, and we regard it as a very useful tool for making steels of high quality.

Dr. **J. White** (Refractories Department, Sheffield University) : I propose to confine my remarks to the Contamination Symposium. During our work in Glasgow on the Fe–H_2S–H_2 equilibrium, we had evidence of the formation of a volatile silicon sulphide, which we thought was probably SiS_2. By a coincidence, our paper‡ appears in the same issue of the *Journal* as the Symposium.

We were passing H_2–H_2S mixtures over liquid iron in a reaction chamber made of alundum, and found that silicon was picked up in rather considerable amounts by the iron. Incidentally, this seemed to upset the value of the equilibrium constant, though this effect was neglected by Chipman and Ta Li in their earlier work on this system. In addition, our outlet tube tended, continually, to become choked with a deposit which we found was mainly silica. We never obtained such deposits when working with hydrogen alone, and were forced to conclude that the presence of sulphur was responsible. After searching the literature, we decided that SiS_2 was probably formed by reaction with the silica in the refractories we used.

The Symposium has cleared up for us, some rather puzzling phenomena which we have encountered with platinum / platinum - rhodium thermocouples over several years. On occasions we have found them when melting at several-hundred degrees below the melting point of platinum, when used in reducing atmospheres in reaction tubes closed at the ends by rubber bungs. In use, these bungs became rather warm, and it now seems probable that some volatilization of sulphur occurred from them. In the earlier part of our work mentioned, we tried to suspend our crucibles by platinum wires in the H_2–H_2S atmosphere, but the suspensions invariably broke in the hot zone, and melting took place in some cases. When heated in a bunsen burner later, these wires were extremely hot short, and flew to pieces when tapped. At the time we had no explanation of these failures, and attributed them to some effect of the reducing atmosphere.

More recently I encountered a similar phenomenon in an industrial installation where platinum thermocouples were put in kilns for firing refractories. The installation consisted of an internal impermeable sheath containing the thermocouple, surrounded by an external permeable sheath of carborundum. The thermocouples performed well during the first burn, but several of them failed during the second, and it was found that the inner sheaths of these had cracked, and melting of the thermocouple points had occurred though the temperature was at no time above 1450° C. This was again attributed to some effect of the reducing atmosphere which would exist inside the carborundum sheath. The real reason can now be appreciated, and is that sulphur compounds in the furnace gases would be able to diffuse through the carborundum sheaths, thus gaining access to the thermocouples.

I should like to mention one other example of a somewhat obscure phenomenon, on which the silicon sulphide reaction seems capable of throwing light. After our paper, referred to above, was published, we had a communication from Dr. Riley, who with Mr. Preece of Leeds University,

* T. Land, *Metal Treatment*, 1941–2, Autumn, pp. 107–110 and p. 113.

† D. Mansterfield and J. R. Thurston, *Journal of the Iron and Steel Institute*, 1946, No. II, pp. 61–65 P.

‡ J. White and H. Skelly, *Journal of the Iron and Steel Institute*, vol. 155, Feb., pp. 201–212.

presented a paper to the Institute some two years ago on the scaling of steels in atmospheres containing nitrogen, carbon monoxide, water vapour, and small additions of sulphur dioxide. He wrote that they had obtained similar deposits to ours in the outlet ends of their tubes, though the conditions were apparently entirely different, since their atmospheres were oxidizing. Actually, calculation shows that their atmospheres would be only slightly oxidizing to iron at 1150° C., their experimental temperature, but even so, to give a reasonable free-energy value for the formation of SiS_2 it seems necessary to assume that the carbon of the steel was lowering the effective oxygen pressure at the metal surface, thus promoting SiS_2 formation. This is consistent with the findings of Dr. Chaston, Mr. Edwards, and Mr. Lever, that carbon as well as sulphur is necessary to cause contamination of platinum at 1200° C. Under our own conditions this was presumably unnecessary owing to the higher temperatures and the highly reducing nature of the gases. Now, if carbon of the steel promoted the reaction, it seems likely that silicon of the steel would contribute to the formation of the SiS_2. Hence, it might be expected that steels which rely mainly on their silicon content for scaling resistance, would be particularly susceptible to SO_2 in the atmosphere. Examination of Preece and Riley's results appears to indicate that this is indeed the case, *e.g.*, their 4%-silicon steel and their 3%-silicon, 12%-chromium steel are decidedly the most affected.

The **President** (Dr. C. A. Desch, F.R.S.) : At Sheffield University we had a 2½-ton open-hearth furnace, which was run for a period every year ; and we had a group of students standing round at the moment of tapping, taking readings through optical pyrometers. As Mr. Hall will understand, we used to get some rather diverse results. In steelworks we are now using the Schofield-Grace immersion pyrometer, and it has been possible to exercise a very valuable control on the production of steel. That is one of the best services which the Research Committees have rendered to the steel industry, and the co-operation of the National Physical Laboratory has been exceedingly valuable.

AUTHORS' REPLIES

Mr. **J. A. Hall** (in reply) : I was particularly pleased to hear of Dr. Main's interest in this paper, because I took my first steps in temperature measurement in his department at Hadfields some thirty years ago, and I feel that to come round to this work once again, with much of it done at Hadfields, has been a great pleasure to me. As regards the attempted analyses of these frequency curves into components, I did try that, and I have a copy of the diagram at the Laboratory. It did not occur to me to think of it in terms of the peak at each side and to regard the big one in the middle as subsidiary, and that is probably where I went astray. I abandoned the idea of attempting to analyze these curves in that way because I felt that the observations were not good enough. If we are to attempt to analyze the curves we must get better resolution. We cannot—photographic emulsions being what they are—use a smaller scanning spot than 0·1 mm., for we would flatten everything out because of the graininess of the emulsion ; but we could use a 35-mm. film, which would give us something like a five-fold increase in resolution, because we could occupy a much bigger area of film. On the other hand, that would involve more apparatus and a good deal more expense, and we did not feel that was justified at that moment.

With regard to Fig. 58, Dr. Main points out that there is an apparent discrepancy there, in that the peak of the curve leads to an apparent true temperature of 1511° C. as against a dip-couple reading of 1576° C. I have not, unfortunately, got the figures with me, and for reasons of compression they are not included in the paper ; but that was one of the examples where the tap-hole, which was imperfectly opened by means of an oxygen lance, gave the rather meagre stream which I showed on the screen this morning. The stream is being chilled by the launder and is obviously very much lower in temperature. A second attempt to open the tap-hole further with the oxygen lance, meant that the optical temperature and photographic temperature rose by some 30° or 40° C. ; I will give the exact figure in my written reply.

This work has shown that it is useless to send somebody without experience of the conditions, into a melting shop or a foundry, with an optical pyrometer, in order to take readings. He may be a skilled observer in the laboratory, or he may be somebody who has never seen an optical pyrometer before. In any case, he will probably fail to get good readings until he has had considerable experience in knowing what he is looking at and what to expect. I hope that some of this work will be helped by the training of observers. That is why I emphasized, in presenting the paper, my indebtedness to Mr. Knowles, for the benefit of his experience in taking many optical readings under these conditions.

Mr. **E. W. Elcock** briefly replied to the discussion on the Symposium, which would be answered in correspondence by the authors of the various papers. He expressed appreciation to Mr. Fornander for his valuable work on liquid-steel temperature determination in Sweden, and welcomed the opportunity afforded of mutual collaboration on the subject.

Joint Discussion on the Papers—

THE OPERATION OF OPEN-HEARTH FURNACES WITH COKE-OVEN GAS,* *by D. Kilby*

and—AN EXPERIMENTAL FURNACE FOR THE INVESTIGATION OF OPEN-HEARTH FURNACE COMBUSTION PROBLEMS,† *by A. H. Leckie, J. F. Allen, G. Fenton, J. R. Hall, and C. Cartlidge*

Dr. **A. H. Leckie,** in presenting the second paper, expressed regret at the absence of Mr. J. R. Hall and Mr. C. Cartlidge, who were very busy at the moment converting furnaces to use oil. The authors had endeavoured to acknowledge in the paper the practical help they had received from many people in the industry, but in addition they wished to express their appreciation of the encouragement throughout the work which the authors had had from Mr. Myers, Head of the Steelmaking Division of the British Iron and Steel Research Association, and from Mr. Edgar Evans, Head of the predecessor of the British Iron and Steel Research Association, under whose regime the work was started. At the beginning of the work, he added, they had had very constructive help from the President, who at that time was on the guiding committee. They were going to get the furnace going again after rebuilding, and anyone interested would be very welcome at the plant.

DISCUSSION

Mr. **W. Geary** (Appleby-Frodingham Steel Co., Ltd., Scunthorpe) : The work done by Dr. Leckie and his colleagues at Shelton is an outstanding example of systematic study of fundamental principles in the field : Mr. Kilby's paper deals in a practical way, on steelmaking furnaces, with several of the elusive variables that Dr. Leckie's team was successfully isolating.

The work on the small furnace at Shelton will, I think, prove to fill a very special place in the field of practical furnace work. It was explained in the paper that the sponsors of the programme considered very carefully whether they should work at high temperatures or at low. I think it must be agreed that they were right in working below steelmaking temperatures. Once the decision about temperature had been reached, it became possible to plan the experiments in detail, and I think that the experimental work was thought out most carefully indeed, and just as carefully done. I think we will all admire the way the work has been done and that most steelmakers will be able to make some use of the results.

I was pleased to hear Dr. Leckie, in his introduction, mention the common ground that existed between the work done at Shelton and that reported by Chesters and Thring in Special Report No. 37.‡ The United Steel Companies' team and the B.I.S.R.A. team, under Dr. Leckie, were each aware of the other's work, and it was realized that whatever the results of the two researches, they could not fail to be mutually helpful. As a result of these researches, it is not an exaggeration to say that the last two years have seen more advance in our knowledge of the advantages of various port designs than did the previous twenty.

The results given in the paper show that all the main fundamentals of combustion conditions in the conventional open-hearth furnace have been studied, and it is probably safe to say that enough is now known of these fundamentals to justify an extension of the work and the building of a small experimental furnace that will work up to full temperature and actually make steel.

But even without this further step, the paper as it stands, offers enormous help to those operators whose working lives are devoted to seeking and establishing, on their furnaces, the combustion conditions that will give them the best results.

I would like to commend Mr. Kilby on his very good paper on the operation of open-hearth furnaces with coke-oven gas. The subject matter is exceptionally well set out, and gives just the sort of detail a furnace operator wants to know.

Some years ago I had the task of starting-up a number of Hoesch furnaces, and soon found, as Mr. Kilby did, that the coke-oven-gas furnaces were less troublesome to operate than the other furnaces in the shop. In our early days the ability of the furnaces to make good quality steel was questioned, but investigation quickly showed that any steel that could be made in a producer-gas furnace could be made equally well when the fuel

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* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 3–20.

† Ibid, 1947, vol. 155, Mar., pp. 392–422.

‡ J. H. Chesters and M. W. Thring, *Iron and Steel Institute Special Report No. 37*, 1946.

was coke-oven gas plus illuminant. This is in line with Mr. Kilby's own experience, and he also found, as we did, that the coke-oven-gas furnace, besides giving a steel quality equal to that from the other furnaces, would actually give lower operating costs.

A manager who thus finds his furnaces converted to coke-oven-gas firing usually wonders why the process is not more generally used. The answer normally lies in the question of fuel balance. In many integrated works there is not a sufficient surplus of coke-oven gas available, and in those cases it is usually more economical to fire the open-hearth furnaces with mixed gas.

Considering the furnace itself, there is, of course, one particular in which it excels all others; it provides the complete answer to the need for compromise that embarrasses all designers of conventional furnaces. It has the small entrance port for the fuel, and the large exit port for the waste products.

Probably the most important feature of the furnace is the burner itself. It will be remembered that up to a few years ago, the Hoesch was the most popular form of coke-oven-gas furnace, but in the last few years there has been a tendency to abandon this design and instal a composite burner of the type that is described in this paper.

An interesting problem is the degree of flexibility that can be obtained with a burner of this type. I am aware that there is a good deal of research and experiment being done with burner design, but I do not think there is at present a composite burner capable of burning, with equal efficiency, either 100% gas or 100% liquid fuel. One must probably determine the range within which variations are desired, and design the burner accordingly. Perhaps the author would be kind enough to tell us whether he has any special means of improving burner flexibility.

In connection with fuel variation, the author suggests, on p. 4, that circumstances could arise where it is cheaper to avoid the use of an illuminant, and use a greater amount of coke-oven gas even at the expense of a higher fuel consumption. In my own opinion this statement, as it stands, is a little misleading, because it would not be a reasonable commercial proposition to work without an illuminant unless very high proportions of scrap were being used in the charge.

Mr. Kilby's account of his experiments with burner size, form an interesting link between the two papers under discussion. He found that he obtained better results—which, in effect, means that he got a better heat transfer when he reduced the diameter of the burner. This agrees with the general finding of Dr. Leckie and his colleagues. It was also my own experience that improved working was obtained from the Hoesch furnaces with a progressive reduction in the diameter of the gas burners : the most effective size was the smallest which would admit the necessary quantity of gas at the available pressure.

Another direct relation between the two papers is shown in the discussions on the influence of the calorific value of the gas. Mr. Kilby states that production suffers badly if the calorific value falls below 490 B.Th.U./cu. ft., and this is also confirmed by my own experience. Although a comparatively rich gas still remains, the drop in flame temperature is a fairly substantial proportion of the temperature difference upon which the speed of steelmaking depends.

Can the author give any more information regarding fuel input during the charging period ? The paper states that during charging he admits 60,000 cu. ft. of coke-oven gas per hour. On the 100-ton Hoesch furnaces we were able to burn gas, during charging, at approximately twice that rate, and some tar as well. Have attempts been made to increase the fuel input during this period, or is the 60,000 cu. ft. per hour sufficient to match the ability of the charging machines to put in the cold charge ?

With Mr. Kilby's conclusions, set out on p. 20, I must generally agree. His conclusion 3 says it is highly probable that the all-basic furnace will be the furnace of the near future, and that the temperature fluctuations which cause premature failure can be minimized by leaving some coke-oven gas on in the furnace at the weekend. Personally, I think the all-basic furnace must come ; its coming will be helped by the continuous working week, and possibly by the increased use of coke-oven gas. It is now generally believed that if the roof temperature can be stopped from falling below about 750° C., the peeling should be greatly minimized. I think, however, that to do this through any considerable period between charges would probably take more than a little gas.

Mr. Kilby's conclusion 4 is perhaps incomplete as it stands. He says that little trouble is experienced with foaming charges on the coke-oven-gas-fired furnace as compared with mixed-gas-fired furnaces. In my view, this conclusion should be amended to say " coke-oven gas plus illuminant."

In conclusion, I should like to ask Mr. Kilby if he can give us any more detail concerning the instrumentation of the furnaces, and any figures relating to combustion conditions. Does he measure roof temperatures and pressures ? What concentration of CO_2 does he get in the exit gases ?

I have been very glad, Mr. President, to open the discussion on these two very fine papers, which put before us nearly the whole field of open-hearth-furnace practice.

Mr. **J. Mitchell** (Messrs. Stewarts and Lloyds, Ltd., Corby) : I do not wish to deal with any of the specific points of detail raised in these papers, but I should like to express my appreciation of the amount of work which they describe and the information they give. Dr. Leckie has indicated that there are more parts to follow. With these, and the papers we had from Dr. Chesters and his colleagues last year, I think that we are taking the first groping steps towards a completely new idea of what an open-hearth furnace ought to look like and how it ought to work. A question which many of us have now to ask ourselves is, is there the information now available to allow speculating on a completely new furnace ? Although I am one of the advocates of the one-way furnace, I do not think that all the necessary information has been gathered just yet.

The work of Dr. Leckie and his collaborators was, in part, inherited from the late Iron and Steel Research Council. I think that they have set a very hot pace for the Steelmaking Division of B.I.S.R.A., and there is comfort in knowing that some of the same people are to carry on the good work.

Mr. **R. W. Evans** (Messrs. Guest Keen Baldwins Iron & Steel Co., Ltd., Port Talbot, Glam.) : The thanks of every open-hearth operator are due to Dr. Leckie and his co-workers for the painstaking way in which they have conducted the operations on the Shelton furnace, and to the Shelton Iron, Steel & Coal Company for generously providing the furnace and the apparatus on which these experiments have been conducted.

Dr. Leckie has referred to the difficulties in operating such a small furnace at high temperatures. Possibly steelmakers are not unacquainted with these troubles ; in fact it is due to the high temperatures at which they must operate that most of the difficulties arise.

It is necessary to consider, when working furnaces with inside surface temperatures of round about 1600° C. or higher, what is the effect of the properties of reflection of these surfaces back on to the bath in the actual transfer of heat from the flame to the bath. These effects probably are important, but their influence cannot yet be assessed from the experimental work done up to now.

Another point is that the course of these experiments really approximates to the open-hearth furnace charge which is completely melted and fairly quiet. The plane of the hearth, as exemplified by the flat covering of the steel water tanks, presents quite a different picture from the state of a furnace in which the scrap is piled at random. Possibly, if the tanks were corrugated in a way somewhat resembling an aircooled internal combustion cylinder with vertical fins, the furnace might approximate more to the position where the charge can accept more heat owing to its more intimate mixture or contact with the flame.

With regard to flame luminosity the authors, in a footnote, have stated that heat is transmitted radiantly not only in the range of the visible spectrum but also outside that range. That is true, but to open-hearth operators it appears that the greatest heat penetration of the slag by radiation occurs in the visible part of the spectrum. At any rate we can derive some knowledge from the effect of such luminosity on the damping out of foaming slags. The slag foams badly with a non-luminous flame, but with luminosity the foam goes down, due probably to increased heat penetration of the slag by radiation from luminous particles.

Again, without gas regenerators, the effect of the preheat on both producer gas and coke-oven gas in the production of luminosity is lost. I hope that in the future, as Dr. Leckie has indicated, it may be possible to work with regenerators, and thus get more information on the part which luminosity must, I think, play in the transfer of heat.

I can confirm completely, the findings on the question of the effect of furnace pressure on the transfer of heat. We have done a certain amount of experimentation, and have increased furnace pressures up to 0·07, 0·08, 0·09, and 0·1 in. (W.G.) to see the effect, not only in transfer of heat and speed of working, but also on the furnace itself. On an oil-fired furnace we have been able to go up to 0·08 in. (W.G.). That is a relative figure, because the furnace has a roof approximately 7 ft. above the bath ; but above 0·08 in. we could not go, due to wear on the front linings, back linings, and roof. On another furnace, Venturi type, gas fired, we have gone up to 0·09 in., but there stopped, because of the diverse effect on wear all over the furnace : but putting up the pressure from 0·07 to 0·09 in. (W.G.) on that furnace has given us another charge a week, though it remains to be seen for how long the furnace will last.

Mr. **R. Whitfield** (The Incandescent Heat Company, Ltd.) : Mr. Kilby's paper is an excellent and a very practical contribution to open-hearth-furnace industry and technique : it is a good addition to the Institute's publications in view of the recent paper by Dr. Chesters and Mr. Thring.

Why atomize the pitch–creosote by steam ? There are three principle ways of atomizing oil ; *viz.*, (i) pressure air, (ii) pressure steam, and (iii) pressure oil.

Where steam is available, atomization by this means seems the most economical method. My own experience dictates high-pressure air of the order of 100 lb./sq. in. The air necessary for

atomization is about 7% of the total required for combustion ; the balance can be preheated in the usual way. The atomized air initiates the combustion of the oil efficiently.

Has the system of combustion of oil been investigated ? In effect we have $C_xH_y + H_2O$ (a water–gas reaction) ; later O_2 is added *via* air from the ports. The operations are at very high temperatures. Finally, the resultant gas is $CO_2 + N_2 + H_2O$, with endothermic and exothermic reactions between the initial and final stages.

If no free carbon is desired, then by studying the combustion of hydrocarbons by the hydroxylation theory :

$$C_xH_y + \text{part } O_2 = pCO + qH_2.$$

Then :

$$pCO + qH_2 + \text{balance } O_2 = CO_2 + H_2O.$$

Thus a reducing atmosphere with oil firing is possible.

Is it possible with the high temperatures prevailing in open-hearth practice, that the above reaction is masked ?

Has any experience shown trouble from heat radiating on to the burner equipment not in action ? I note that the steam is kept on, and presume that cooling of the burner is the objective, together with the pressure influence in keeping the hot products of combustion away from the burner.

I have installed automatically controlled oil burners working on a swinging system ; as the motorized burner swings back, the oil is cut off by a valve. In isolated instances the whole of the reversal system has been operated by automatic temperature control based on the regenerators.

Were the regenerators insulated ? In my experience, the extra expense has proved an excellent investment. In one installation on one set of regenerators only, the insulated walls were rendered air-tight by several applications of hot silicate of soda (water glass). Thermometers were then placed at exactly similar positions on both sets of regenerators, and the temperatures recorded. They started at a temperature of about 105° C. : the sealed side kept in the neighbourhood of that temperature, but on the other side the temperature gradually rose in the course of a few weeks, due to the gradual infiltration of fine dust into the pores of the insulating bricks, thus destroying or reducing the insulating property. Obviously, the heat radiation on both sides are very different, and considering the usual large area, the total difference may be considerable.

I do not think that sufficient emphasis has been placed on port design. That described in the paper seems admirable for liquid-fuel firing.

The paper is admirable in every way because it is so practical, and Mr. Kilby bids well to continue a very honourable family tradition.

The **President** (Dr. C. H. Desch, F.R.S.) : Mr. Whitfield wrote up his first partial equation on the board and asked what reactions occurred after mixing the oil with steam. I should like to mention that on that subject a great deal of work has been done recently, and it would be a good thing if at some time it were made better known to this industry. If he were to ask Sir Alfred Egerton, of the Imperial College, he would find that the amount of information available was considerable.

AUTHOR'S REPLY

Dr. **A. H. Leckie** (in reply) : I was very glad to hear from Mr. Geary that our recommendations on port size have been confirmed in his own experience, and he has pointed out that they have been confirmed in many other cases. He also drew attention to the importance of instrumentation, which I rather neglected to stress in presenting the paper ; but one thing that our work did show, was that the control of the furnace is more important that the design of it. If one correctly controls an old furnace, one will probably get better results than if one builds a new furnace without instruments and does not attempt to control it.

I was glad to hear of Mr. Mitchell's interest in the possible future of the open-hearth furnace, and even his mention of the one-way furnace. He is Chairman of the Panel which governs all this work, and his interest is specially encouraging.

Mr. Evans referred to the generosity of the Shelton Company in providing facilities for this work. We have acknowledged that generosity on many occasions. He also pointed out nearly everything which can be said against low-temperature work from the theoretical point of view. I think that we can sum it up in this way : that our experiments have been done on the mixing and burning of air and gas under conditions which are very much more unfavourable than in practice. At high temperatures the gases will burn more quickly, owing to the chemical reactions going faster. They will radiate heat much more readily at high temperatures, owing to the ordinary laws of radiation. What we say, therefore, is that if we find the conditions which give good heat transfer at our low temperatures, we shall be safe in saying that these conditions will in the main apply at the high temperatures, the only difference being that the heat transfer will be even better at high temperatures. We had considered the simulation of piled-up scrap by placing vertical steel cylinders on the surface of the hearth tanks but decided that this would introduce another variable—the turbulence set up by impact with these obstacles, together with possible catalytic surface combustion—so that the effect of port design and furnace operation would be obscured.

Joint Discussion on the Papers—

THE APPLICATION OF SLAG CONTROL AND AN INVESTIGATION OF BASIC OPEN-HEARTH SLAGS* *by T. Fairley*

and THE EFFECT OF TEMPERATURE ON THE PHOSPHORUS REACTION IN THE BASIC STEELMAKING PROCESS† *by K. Balajiva and P. Vajragupta*

DISCUSSION

Mr. **N. H. Bacon** (Messrs. Steel, Peech and Tozer, Sheffield) : I am very pleased to have the privilege of opening the discussion on these two most interesting papers, because they deal with an aspect of steelmaking which in its own way is just as important as furnace design or the question of fuel economy ; I feel that nothing like the concerted attention has been given to this question of slag–metal reactions which has been given to the other phases of steelmaking. Both these papers deal with the subject of slag–metal reactions. One of them deals with the ways and means of obtaining a slag of some desired constitution, which is a very difficult matter, as all steelmakers know full well. The other paper deals with the slag constitution required to bring about a desired reaction. It must be admitted that our knowledge on both aspects is still very limited, although it is true that compared with the position thirty years ago considerable progress has been made.

Dr. Fairley has referred at some length to the formulæ which can be used as a measure of the basicity and says that he prefers $CaO/SiO_2 + P_2O_5$, as do many other workers. In Figs. 9, 10, and 11 he plots the three formulæ, one against another, but since all three of them are at the best only very rough estimates of basicity, it does not seem to lead very far to compare them in this way. Most melting-shop men will agree that the best measure of basicity is the slag's capacity for reducing the sulphur content of the metal bath, and they know that if a slag is basic enough to reduce the sulphur the phosphorus will give no trouble.

Taking then the ratio of slag-sulphur-percentage/metal-sulphur-percentage as the best criterion of slag basicity, Fig. A shows how very unsatisfactory these three formulæ are as measures of basicity.

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Feb., pp. 161–171.

† *Ibid.*, 1947, vol. 155, Apr., pp. 563–567.

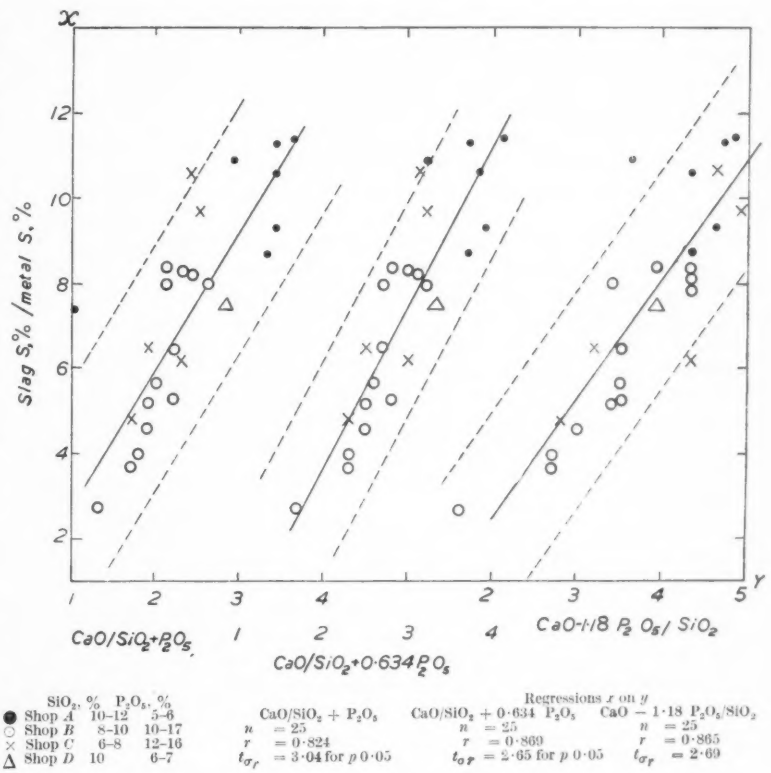

FIG. A—Basicity formulæ plotted against slag-sulphur-percentage/metal-sulphur-percentage ratio

TABLE A—*Comparison of Equations*

Bath Carbon, %	SiO_2, %	CaO, %	P_2O_5, %	Total Fe as FeO, %	MnO, %	Slag-Sulphur-Percentage/Metal-Sulphur-Percentage	Bath Phosphorus, %	Temp., °C.	According to Equation of:	
									Authors*	Schenck
0·22	13·8	53·6	7·7	10·2	4·6	7·5	0·035	1627	0·051	0·036
0·65	14·0	52·1	5·2	14·1	4·6	14·0	0·024	1597	0·028	0·024
0·10	11·6	50·7	4·6	16·7	4·1	9·0	0·017	1627	0·021	0·016
0·75	11·8	57·8	6·5	10·9	4·4	13·8	0·030	1595	0·030	0·034
0·13	9·8	51·4	3·8	21·2	6·3	10·0	0·011	1610	0·011	0·009
0·73	15·5	54·9	4·5	9·0	4·4	9·7	0·035	?	0·065	0·035

* Balajiva, Quarrell and Vajragupta

What is very badly needed—and probably only the physical chemist can give it to us—is some means of deciding from the chemical analyses which we can obtain as the charge melts, a formula which will bear a more accurate relationship to the true basicity of the slag. Dr. Fairley in his paper mentions 18% $SiO_2 + P_2O_5$ as desirable if 0·035% (maximum) of phosphorus is wanted. He does not mention sulphur. Perhaps that is an oversight.

The very interesting papers* on the phosphorus reaction deserve most careful study. There is one criticism that I would make, and that is in connection with the effect of alumina in the slag. It is a very interesting point. The investigators found that in the presence of higher percentages of alumina—7 or 8%—the capacity of the slag to absorb phosphorus was considerably reduced, and so they made a statistical test, using Fisher's *Z* test, to see whether this difference between the two groups of slags, *i.e.*, the normal ones with 2–3% of alumina and those with 7–8%, was significant. The test showed that the data were not sufficient to prove any significant difference, and therefore the investigators included these 12 high-alumina slags with the rest in working out their equations. I think that they made a mistake there, because while the statistical test showed that there were not sufficient data to prove a significant difference, it by no means proved that there was no real difference. It would appear from the data that there probably is a significant difference.

The authors offer for our consideration an equation for determining the phosphorus content of the metal which is very simple indeed compared with that of Schenck, which they appear to dismiss rather lightly in the paper. Many of us find Schenck very useful ; they apply his rather formidable equation to their experimental data and find some lack of agreement. I myself worked out some of the results, just as a check, and there was a similar disagreement. For example, in three melts the authors found 0·076, 0·027, and 0·020% of phosphorus, and according to Schenck there should have been 0·034, 0·018, and 0·017%. I took the last two in their list, 0·059 and 0·027%, and according to Schenck there should have been 0·022 and 0·008%. I think, however, that any practical steelmaker, looking at these particular slag analyses, would agree that in normal practice the figures would be much nearer to Schenck's than to those of the authors.

We have found that Schenck's formula gives very good results indeed when applied to open-hearth furnaces. These experimental melts were made under conditions different from those of ordinary steelmaking conditions, with no oxidizing atmosphere, and the bulk of slag may also have made a difference. From a series of basic open-hearth slags recently investigated, I picked out half-a-dozen haphazard, three of low-carbon steel and three of high-carbon steel, and applied to them the equation offered for our consideration by the present authors. The results are shown in Table A.

Schenck's equation for sulphur also gives satisfactory results. In the case of the present authors' equation, there is good agreement except in two cases, one in the low-carbon group and one in the high-carbon group, and in both cases the slags had an unusually low Fe content.

I should like to congratulate all the authors on their very useful contribution, and to make a plea, particularly as Mr. Mitchell is here, that more should be done to encourage co-operative work on this aspect of steelmaking, *i.e.*, slag–metal reactions and slag control. I hope that Dr. Leckie's wish will be realized and that he gets his little furnace making steel, because that should provide a very useful means of studying these reactions.

The **President** (Dr. C. H. Desch, F.R.S.) : Those who have followed the literature of slag composition will agree, I think, that the curves presented by Dr. Fairley really do seem to fit the facts. The scatter in experiments of this kind is usually much greater.

* K. Balajiva, A. G. Quarrell, and P. Vajragupta, *Journal of the Iron and Steel Institute*, 1946, No. I, pp. 115P–145P ; K. Balajiva and P. Vajragupta, *ibid.*, 1947, vol. 155, Apr., pp. 563–567.

Dr. **A. G. Quarrell** (British Non-Ferrous Metals Research Association, London) : Dr. Fairley has carried out a statistical investigation of a large number of melts, and by rationalizing the procedure adopted has been able to effect a considerable improvement in the steelmaking technique employed in his works. Although this treatment has led to a considerable improvement in technique, I think that Dr. Fairley would be one of the first to admit that it is unlikely to increase our understanding of the physical chemistry of steelmaking.

Dr. Balajiva and Dr. Vajragupta, on the other hand, have used a laboratory method to investigate in such detail as is at present possible the reactions occurring between slag and metal, and I think it must be admitted that they have thrown some light on the problem and have increased our knowledge of the chemical principles underlying the dephosphorizing process, although it is true that they have not been able to give a completely satisfactory treatment, owing to lack of information on the constitution of liquid slags. I thoroughly agree with Mr. Bacon about the need to check such investigations with practical results obtained in the steel melting shop. There is, however, a very great scarcity of data suitable for checking any new formula or equation which may be developed as a result of laboratory work, and I should like to ask that, wherever possible, when papers are written dealing with industrial practice they shall give full details of the slag and metal analyses, together with the temperatures at which the samples were taken. If you search the literature you will find that it is exceedingly difficult to get more than a mere handful of results which contain all the information which is really necessary for checking equations such as those developed by the authors.

The work which Dr. Balajiva and Dr. Vajragupta have reported is, I think, the first attempt in this country to investigate slag–metal reactions in the steelmaking process on a fundamental basis on a laboratory scale, and to cover a much wider range of slag compositions than is normally encountered in steelmaking practice. As both authors are shortly to return to their own country, I hope that steps will be taken to see that the lead which they have given will be followed up, and that the technique which they have developed will not be allowed to lapse. There are large numbers of problems connected with steelmaking which are crying-out for investigation, and which could very well be investigated economically on this small scale by the technique which the authors have developed. It would be a great pity if this work was just allowed to lapse.

Mr. **J. Mitchell** (Messrs. Stewarts and Lloyds, Ltd., Corby) : I think it is a pity that this most important subject of slag control has come at the end of a very busy day. There are two points that I want to make. First, I want to ask about the necessity for control. We are so busy trying to get the open-hearth furnace to behave in the same way during a series of consecutive operations that we sometimes do not stop to ask *why* we have to do it ; we are more interested in *how*. Second, I want to present to you what may be thought a rather curious feature of basic slags in general. If we superimpose on Dr. Fairley's histogram of basicity ratios the same ratios arising over three years at Corby, as has been done in Fig. B, I think he will agree that the basic Bessemer slags are evidently very much more stable in this respect. Of Dr. Fairley's slags, 98% have ratio values within the range 2·1–3·1 ; 98% of our slags lie within the limits 1·9–2·1. This stability from the once-despised "uncontrollable" basic Bessemer process shows up, in one aspect, what can be expected from control, as such, within the larger framework of the process itself.

Dr. **L. Reeve** (Appleby-Frodingham Steel Co., Scunthorpe) : I should like to draw attention to one method of slag control which has not been referred to by Dr. Fairley in his very useful résumé of the different methods in existence. I am referring to the references which have appeared in the American literature during the last two years to the use of a *p*H method for the determination of slag basicity. The slag, crushed to through 40-mesh, is shaken with distilled water for several minutes, and the *p*H of the suspension determined by means of a glass electrode.

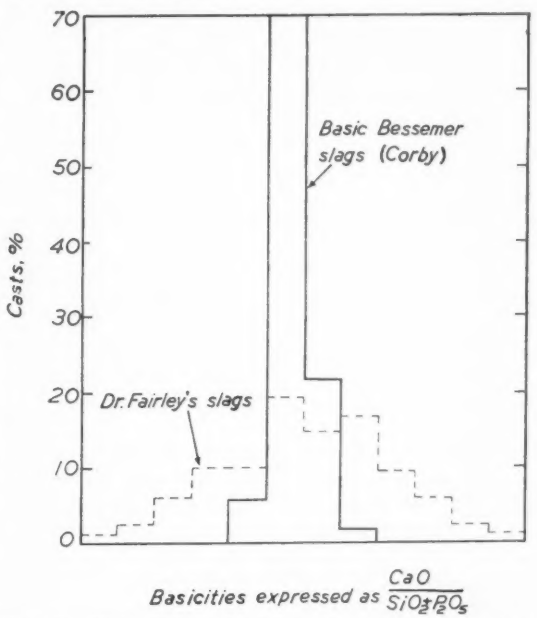

FIG. B—Histogram of basicity ratios at Corby superimposed on replot of Fig. 8

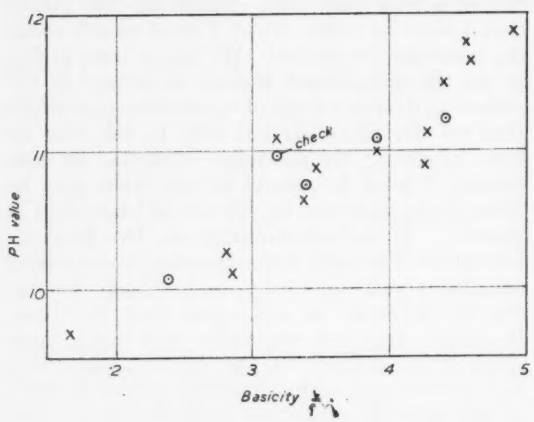

FIG. C—Relationship between slag basicity and *p*H value

We have done a little work on this method at Appleby-Frodingham which suggests that the method has promise, though a good deal more investigation is obviously necessary to confirm the preliminary results, some of which are shown in Fig. C. The basicity expressed as $CaO - 1{\cdot}18\ P_2O_5/SiO_2$ has been plotted against the *p*H as ordinate. I note that Dr. Fairley does not like this method of expressing basicity, but a similar degree of scatter is obtained when the basicity is calculated by the other methods he has mentioned. The whole method does not take more than 15 min. from receipt of the sample, and I think that there is a good deal of promise in it. It is considerably more accurate than the "slag pancakes," which we have tried and found almost entirely useless for our practice, or the colour methods, which are difficult to assess under shop conditions. Although the results are perhaps not as accurate as straight chemical analysis, they are approaching that degree of accuracy.

There is a further point of some importance in connection with the matter. Although it is true, as Dr. Fairley has stated, that we really do not know the fundamental factors controlling the basicity of a slag, I think that a little light has been thrown on the subject by the excellent work of the late Dr. Jay, whose early death has been a real loss in this field. He has shown that the basicity of the slag is related to the actual percentage of free lime in it as determined by X-ray tests. He has carried out X-ray tests on half-a-dozen of the slags in Fig. C from which it appears that there is a direct relation between the *p*H values and the free lime as determined by the X-ray method. I think that more attention should be paid in this country to the possibilities of this quick method of determining basicity.

I want to mention also that there is a correlation between the *p*H of a slag and its desulphurizing power, as measured by the ratio of sulphur in the slag to sulphur in the metal. I have not been able to complete the scatter diagrams illustrating these points in time for this meeting, but I hope to collect them together, and, along with further details, present them as a short paper to this Institute in the near future.

Dr. **J. White** (Refractories Department, Sheffield University): My interest in these papers is mainly from the theoretical point of view, rather than from that of actual steelmaking, but perhaps I need not apologize for that, as several of the previous speakers have emphasized the need for more knowledge of the liquid slag. Some years ago I tried to work out a constitution in terms of the law of mass action which would explain slag–metal relationships.* The basis of the method used can be explained by means of a relatively simple example. If you have a pure FeO–MnO slag in contact with liquid iron you can determine both L_{FeO} (the partition coefficient of FeO between slag and metal) and K_{Mn} (the manganese equilibrium constant) in terms of the total concentrations of the reactants in slag and metal. If now you take an FeO–MnO–SiO_2 slag saturated with silica, as was done by Korber and Oelsen, you can again determine L_{FeO} and K_{Mn} in terms of the total concentrations of the reactants, and these are again apparently constant with varying FeO/MnO ratios. The actual values are, however, different from those obtained with the silica-free slag, showing that the quantities evaluated cannot be regarded as true physical chemical constants.

The basis of my own attempt was to attribute the difference to the formation of silicates in the slag. That idea was not new, but I tried to put it on a quantitative basis. Starting with dissociation data on liquid ferric oxide, alone and in the presence of lime and silica, the dissociation constants of the calcium ferrites, calcium silicates, and ferrous silicates in the slag were calculated. Then, knowing the dissociation constant of $FeO.SiO_2$, the dissociation constant of $MnO.SiO_2$ was calculated from Korber and Oelsen's data on silica-saturated slags. The significant point was that the constants so evaluated enabled the slag–metal composition isotherms of Korber and Oelsen to be fitted very closely, and the difference between the "apparent" values of L_{FeO} and K_{Mn} with silica-saturated slags and the values of these constants with FeO–MnO slags to be accounted for. In particular they predicted that at 50% of silica or over the "apparent" values of L_{FeO} and K_{Mn}, in terms of the total concentrations of the reactants, should be constant with

* *The Iron and Steel Institute*, 1938, *Carnegie Scholarship Memoirs*, vol. 27, pp. 1–75.

varying FeO/MnO ratios, though this would not be the case at lower silica contents. I still regard these as highly significant findings, as showing that observed variations in slag–metal relationships could be accounted for in terms of the mass-action dissociation constants of compounds considered to be present in the liquid slag. Further, using the dissociation constants for calcium, and for ferrous and manganous silicates, it was found possible to predict the variation in K_{Mn} between acid and basic slags, and to account for the relationship indicated by Tamman and Oelsen from an examination of furnace slags.

The points I wish to make are these. Firstly, there was then no laboratory data sufficiently general in scope regarding the phosphorus equilibrium to enable calcium phosphates in the slag to be treated, and the simple assumption was made that $3CaO.P_2O_5$ was completely undissociated in basic slags. The present paper by Drs. Balajiva and Vajragupta, and the earlier one with Dr. Quarrell, provide just the type of data required, and it should now be possible to re-examine the question of the constitution of basic slags. Secondly, I should like to draw particular attention to the fact that in the earlier paper a maximum was shown to occur in the $(P_2O_5)/[P]$ ratio at a critical (CaO)/(FeO) ratio in the slag. I believe that the authors were the first to demonstrate unequivocally that such a maximum exists, though such a maximum is inherent in the relationship indicated by Schenck (*see* Fig. 35 of the authors' first paper). The results of Winkler and Chipman, whose paper appeared about the same time as theirs, appear to indicate the same thing, though not nearly so explicitly. Such a maximum is a direct consequence of the law of mass action, since (CaO) and (FeO) occur as a product in the denominator of the mass-action expression for the equilibrium constant. For approximately constant (CaO) + (FeO) this product will reach a maximum at a critical (CaO)/(FeO) ratio. I feel that this goes far to substantiate the view that slag constitution should be expressible in terms of the law of mass action, and hence that the activities of the reactants in the slag–metal reactions should be calculable. Admittedly there are difficulties at present in reconciling the conception of molecules in the liquid slag with that of the structure of liquid silicates derived from X-ray work.

Lastly, in their first paper the authors deduced by a somewhat arbitrary method a constitution for the liquid slag which enabled them to suggest a value for the phosphorus equilibrium constant in terms of the third power of the concentration of " free " CaO. They have now found that these assumptions are inadequate to account for the results described in their second paper. They have

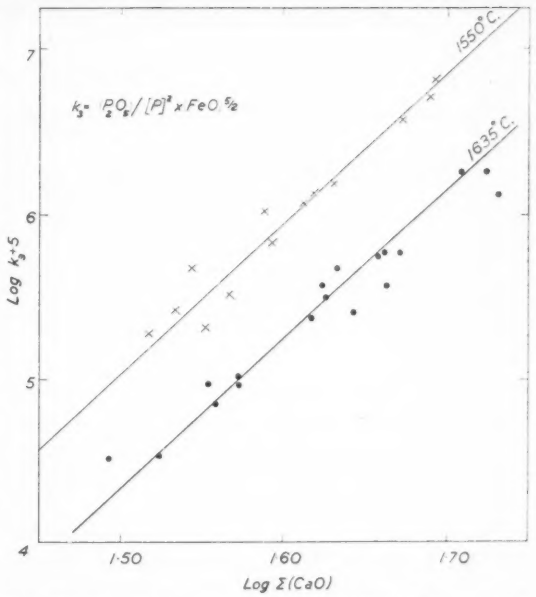

FIG. D—Equilibrium constant using $(FeO)^{5/2}$, according to the results of Balajiva and Vajragupta

no reason to feel discouraged about this, as only a detailed and laborious examination of their results in terms of the law of mass action can yield a completely satisfactory solution, if one is indeed possible. Meantime all attempts to evaluate the equilibrium constant must be regarded as tentative only. Chipman and Winkler, for instance, propose an entirely different value for the constant, though their experimental data do not differ so very widely from those of the authors, simply because they assume a different constitution for the slag. I prefer to regard the authors' proposed value as tentative, therefore, and liable to revision. Their experimental data, on the other hand, are independent of arbitrary assumptions, and should prove a lasting contribution to the subject.

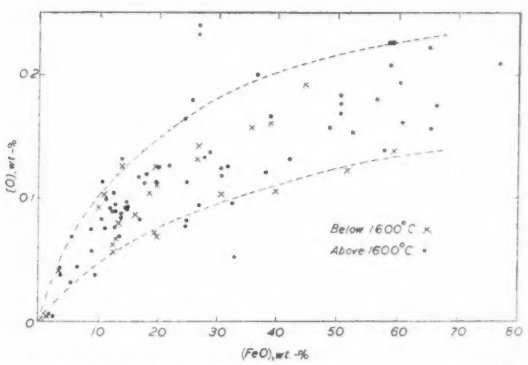

FIG. E—(FeO) plotted against oxygen content, according to the data of Winkler and Chipman

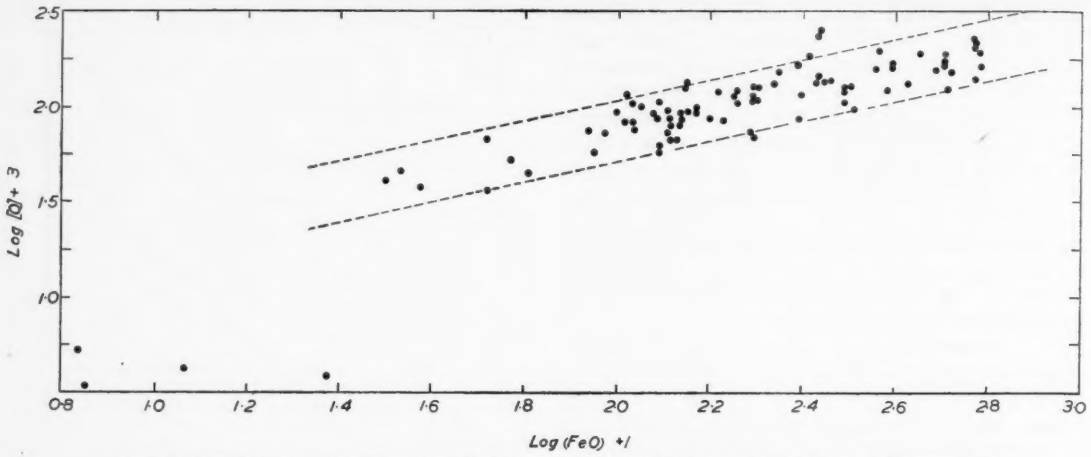

FIG. F—Log [O] plotted against log (FeO), according to the data of Winkler and Chipman

Mr. **W. L. Kerlie** (Messrs. Stewarts and Lloyds, Ltd., Corby) : There is one point which I should like to take up in connection with the second paper, and that is the choice of the term (FeO). The authors make out a very good case for the way in which they express the equilibrium constant, but, as shown in Fig. D, I have taken $(FeO)^{5/2}$ and have obtained straight lines, very similar to those of the authors, for temperatures of 1635° C. and 1530° C. ; that is to say, there is very little, if any, greater scatter as the result of substituting $(FeO)^{5/2}$ for $(FeO)^5$. The gradient of both of these lines being 9 would signify that the basicity of the slag will vary as the cube of the lime content, and that the equilibrium constant of the phosphorus reaction depends on the cube of the basicity.

Figure E is based on the recent paper by Winkler and Chipman (mentioned by the present authors) and shows the FeO content in the slag plotted against the oxygen content. It indicates—which may sound somewhat heretical—that the oxygen in the steel is not proportional to the FeO in the slag but depends on the square root of the latter. Temperatures in this case do not seem to matter a great deal, because, no doubt, of many other factors. The slags cover a very wide range of composition.

In Fig. F I have taken the log of the oxygen concentration and plotted it against the log of the FeO. There is a considerable amount of scatter, but it is obvious that there is a definite straight-line relationship. The gradient of the mean through the points is approximately 0·5. There seems something to be said, therefore, for the assumption that the oxygen concentration will vary as the square root of the FeO in the slag. I do not know what the authors think about that, but I put the point forward as being worthy of consideration.

AUTHORS' REPLIES

Dr. **T. Fairley** (in reply) : There is no time to deal with all the points raised this afternoon, and I shall reply in writing. I am very grateful for the interest which has been shown in this subject, and particularly for Mr. Bacon's interest, because I know the work which he and his colleagues have done. Indeed, much of the work of the past thirty years has been theirs. Dr. Quarrell pleaded for full information to be given. I did submit a very formidable list to the Institute, giving details of some 250 slags, and if anyone would like the information relating to them I shall be happy to supply it.

Dr. **T. Vajragupta** (in reply) : I also should like to thank those who have taken part in the discussion, and to reply in writing. Mr. Bacon referred to the effect of aluminium. I think we have made it clear that we have not dismissed entirely the chemical effect of aluminium. The statistical test which we used gave results which show no statistical difference from the straight line which we have put forward, but it will be interesting to study the effect further. I am glad that Mr. Bacon has tried our method and obtained reasonable agreement, but I should like to ask him whether he has taken into account the effect of temperature, because no good agreement can be expected unless the temperatures are more less the same.

Joint Discussion on—

THE FIRST REPORT OF THE ROLLING-MILL RESEARCH SUB-COMMITTEE (Special Report No. 34)*

and on the Papers—FLUCTUATIONS OF THE DISTRIBUTION OF TORQUE BETWEEN ROLLING MILL SPINDLES,† *by E. A. W. Hoff*

and—THE APPLICATION TO SHAPING PROCESSES OF HENCKY'S LAWS OF EQUILIBRIUM,‡ *by E. Siebel*

Dr. **H. Ford**, in presenting the First Report of the Rolling-Mill Research Sub-Committee, said: I was very glad to be asked to introduce this Report, as I was in charge of the researches during several rather crucial years of their development, and the Report summarizes the first stage in this development. It is necessary to point out that the Report was prepared at the end of 1944, and does not summarize the present-day position. Considerable progress has been made with many of the researches during the last two years, and accounts of these are either being prepared now or are already with the Institute for publication.

I may say that this is both the first and the last Report of the Rolling-Mill Research Sub-Committee. This is because the Iron and Steel Industrial Research Council ceased to exist in December, 1944, and the activities of the Rolling-Mill Research Sub-Committee were taken over by the new Rolling-Mill Committee of the British Iron and Steel Research Association. We are fortunate in having as the Chairman of that Committee the President of the Institute, Dr. Desch.

In reading the Report it is important to bear in mind that the original object of these researches was the study of the rolling mill as a machine, *i.e.*, the mechanics of the deformation process, and the engineering aspects of design and operation.

The Report starts with an introductory section by Mr. E. C. Evans. It was largely due to his foresight and enthusiasm that organized rolling-mill research began in this country, and it is impossible to over-estimate the debt we owe to him.

Section 2, by L. R. Underwood, is a survey of the published literature on the rolling process. It was clear from this report that further experimental work was required.

The Sub-Committee originally wanted to obtain completely new research rolling equipment, but the war made that impossible. Through the kind intervention of Professor Andrew, the small experimental mill at Sheffield University was made available for the work. It was decided to take this over, modernize it, equip it with electrical drive and automatic coilers, and to fit complete measuring equipment. Section 3 describes the installation, but since it was written, further equipment has been added for measuring tension, and for complete photographic recording of all the instruments. This has speeded up very considerably the rate at which the experiments can be carried out. Considerable progress has been made with these researches, which have been reported from time to time to the new Rolling Mill Committee of B.I.S.R.A. Reports are in process of publication.

When the mill was put in hand, there was no suitable commercial instrument for the measurement of roll force, which is one of the things that the engineer wants to know. It was therefore decided to devise a new instrument for the measurement of roll force. Since writing this section, the electrical side of the roll-force meter has been considerably simplified for industrial applications, and the instrument has been tried with success in several works. That side of the work is continuing, as the results have been very promising; the instrument is robust enough for industrial use, yet is accurate enough for experimental work in the laboratory.

Dr. Orowan and Mr. Pascoe, in Section 5, have described an approximate method of calculating roll force and torque in hot flat rolling, based on values of yield stress for a number of steels rolled by Pomp and others. The method will give reliable results except where the thickness of the stock is large compared with the length of the arc of contact between the roll and the stock.

Dr. **E. A. W. Hoff** presented his paper, while

* *Iron and Steel Institute Special Report No. 34*, 1946.

† *Journal of the Iron and Steel Institute*, 1947, vol. 155, Jan., pp. 51–54.

‡ *Ibid.*, 1947, vol. 155, April, pp. 526–534.

the paper by Dr. **Siebel** was presented by Mr. **W. C. Hessenberg**. It should be noted that equation (11) of Dr. Siebel's paper (page 530) should read as $\sigma_q = k_f (1 - ln(d_o/d))$.

DISCUSSION

Dr. **C. H. Desch, F.R.S.** (President of the Institute and Chairman of the Rolling-Mill Committee of the British Iron and Steel Research Association) : I have been asked to say a few words in opening the discussion, and first on the historical side. In the introduction to the Report of the Rolling Mill Research Sub-Committee it is mentioned that when the Sub-Committee decided to undertake experimental work it made use of the mill which had been set up in Sheffield University. I should like to refer to that mill. As far back as 1929 it was decided by the manufacturers of cold-rolled strip to present the university with an experimental mill. That was set up through the generosity of the Worshipful Company of Ironmongers, and it was the intention to carry out quantitative work on it. The first subject which was to be investigated was the difference between plain and roller bearings, and therefore the mill was provided with these alternative bearings. We also devised a strain gauge by which the strain during the passage of the material through the rolls could be measured.

Those things had only just been set up when I left Sheffield to go to the National Physical Laboratory, and then the mill remained without much use being made of it for some years. However, when the Rolling-Mill Research Sub-Committee decided to make use of it they transformed it completely, and the account given in this Report shows that a very great deal of ingenuity was exhibited in converting that comparatively crude machine into a piece of real research apparatus.

Since then a great deal of most valuable work has been done, and it has been a good instance of collaboration between the mill managers on the one hand, and on the other the research team working in Sheffield and those who were attacking the problem from a more strictly physical point of view, Dr. Orowan and his collaborators at Cambridge. The combination of those three sets of persons has led to very good results being obtained.

It is quite clear that there is much to be done on the engineering side of rolling and on the study of the physical processes involved in cold rolling ; and even those two very important fields of research leave out of the question the phenomena of hot rolling where, of course, there is a great deal of recrystallization and other complex processes going on during deformation.

The paper contributed by Dr. Siebel recalls the fact that sixty or seventy years ago there was some very active work being done in France, which I think has been largely overlooked. There was a series of papers by Tresca which are quite remarkable in showing the process of deformation by producing curves of the kind shown by Siebel. That was taken up by Hartmann, also in France, and his little book on deformation gives diagrams which are almost identical with those since given by Siebel. The methods of measurement were not, of course, so perfected at that time, and much evidence had to be gathered from the flaking of scale on the surface and, in the early work of Tresca, by the patterns taken up by the fibres in wrought iron ; but I think that a study of those papers will show that the results were quite remarkable for the time.

We have now, of course, the advantage of being able to measure the forces involved in rolling, with great accuracy, because of the great development of electrical measuring instruments.

I think, as I said at the outset, that the papers now presented show the great advantage of complete collaboration between the actual mill managers and the research investigators. The relations between them have been very friendly, and the investigators will agree that they have been given every facility by the firms possessing rolling mills. There is a great deal of work to be done both in the laboratory and also by field studies on existing production mills. I know that certain firms have offered every facility for attaching instruments to their mills to find out what forces are actually operating during the ordinary running of the mills.

I understand that there is a collective contribution to the discussion from the Armament Research Department to be presented by Dr. Maccoll.

Dr. **J. W. Maccoll** (Armament Research Department, Fort Halstead, Kent) : My knowledge of the techniques involved in rolling-mill work is very limited and I am therefore somewhat diffident about taking part in the present discussion. Two of the papers presented this morning are, however, of considerable interest to me as they touch upon a subject in which I am keenly interested ; namely, the mathematical theory of the plastic deformation of solids. Besides being of importance in steel-rolling processes, this subject has, in recent years, become of great importance in civil and mechanical engineering. The subject is also of frequent application in the field of armament research, and as a consequence much of the work of the small theoretical group carrying out research at Fort Halstead on the mechanics of solids is concerned with the theory of plastic deformations. I shall therefore confine

my remarks to some of the work of this group and the relationship of their work to the papers now before us.

Our need for adequate mathematical techniques in dealing with armament problems involving the deformation of solids, become evident in the early stages of the war, and during 1941 we carried out a review of existing knowledge on the subject of plasticity. From this review it became clear that the previous theoretical research, which had been carried out mainly between 1920 and 1930 was, in fact, very superficial, although many problems appeared to have been completely solved. Actually, due to the various assumptions made, the results were usually more qualitative than quantitative in character.

The early researches of our group dealt mainly with non-steady problems involving the propagation of elastic and plastic waves through solids ; since 1944 the main effort has been devoted to the solution of steady or pseudo-steady problems. In these fields Dr. E. H. Lee and Mr. R. Hill have, either in collaboration or separately, carried out numerous investigations which are described in a series of papers now being published in the scientific journals. These papers should be of wide interest as they show considerable advances on the earlier efforts of Prandtl, Hencky, and other investigators of 20 years ago. These advances in outlook will be clear from Mr. Hill's remarks on Dr. Siebel's paper, which is in fact based on the early conceptions of plasticity theory.

From the mathematical point of view it appears that the theory of plasticity has now reached a stage where many two-dimensional problems can be solved with adequate accuracy, provided that the necessary physical data are available. There remains, however, wide scope for further research. Thus very little work has been done on problems involving three independent variables, and problems of this type will probably require special attention in the immediate future. The mathematical difficulties involved in such work are severe, however, and it is not yet clear that the relatively rapid progress achieved in the last few years can be maintained.

In most of the recent theoretical work on steady and pseudo-steady problems it has been assumed that the regions of elastic stress are of small importance, and that the slip-line systems in the regions of plastic flow are uninfluenced by the elastic regions. In many instances this assumption may not be valid, and it is evident, therefore, that new techniques for dealing with such mixed problems will require to be developed. From these remarks it may be concluded that, despite recent advances, the theory of plasticity still offers wide scope for important research which will be necessary before the subject can take its proper place beside the more classical subjects of elasticity and hydrodynamics.

Mr. **R. Hill** (Cavendish Laboratory, Cambridge) : My remarks will be confined mainly to the paper by Siebel. I can best criticize this paper by describing briefly some of the solutions which I have obtained to the main problems which Siebel discusses.

To begin with, let me emphasize the principle which is vital to the solution of any plane-strain plastic problem, *i.e.*, that the stress distribution can only be calculated correctly by simultaneously considering strain-increments, or, what comes to the same thing, velocities of flow. This is obvious in a situation where the boundaries of the material, or of the plastic region itself, are continually altering during the course of the deformation. An example is indentation by a wedge, where the metal surface is continuously displaced during the penetration ; this problem has been solved by Hill, Lee, and Tupper (1947). The principle is much less obvious—in fact it seems to have been quite overlooked—in steady-motion problems where the extent and shape of the plastic region remain constant during the flow, for example, in the steady states of extrusion, wire-drawing, or rolling. For in the plane-strain theory of plasticity there are, as is well known, three equations involving only the three unknown stress components in the plane, *i.e.*, two equilibrium equations and one yield criterion. One might think, therefore, that in a steady-state problem the flow velocities could conveniently be forgotten until after the stresses had been calculated. For this reason Hencky[1] (1923) called the plane problem " statically determinate." His view was followed by Prandtl[2] (1924) and many later writers. The concept of statical determinacy is, however, quite wrong. Generally the stress boundary conditions are insufficient to determine uniquely the plastic region. This is true even when elastic strains can be neglected, so that we know to begin with that the plastic region of large strains is bounded by slip-lines. This happens in most forming processes, provided also that the metal has a sharp yield point. Even with this additional information about the plastic boundary, many slip-line systems can usually be fitted to the stress boundary conditions. Hencky was aware of this, and so is Siebel. What they, and other writers, are not aware of is the way to determine the one slip-line system which actually solves the problem. This is not to be done by choosing the system giving the least load, as Hencky arbitrarily suggested. The correct slip-line system is that for which the corresponding flow velocities (as given by the Levy–Mises relations between the strain-increment and stress

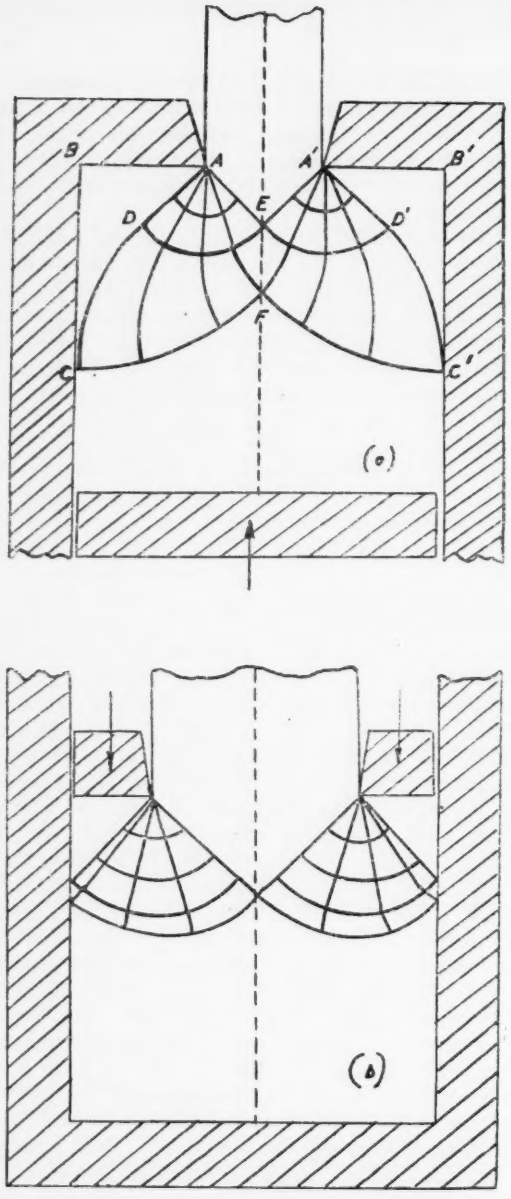

FIG. A—Diagrammatic representation of a slip-line field in (*a*) direct extrusion and (*b*) inverted extrusion

tensors) satisfy the velocity boundary conditions. It is not necessary to insist on this point in a general three-dimensional problem, since here there are less equations involving stresses alone than there are stress components; the relations between stress and strain have then to be used, in any event, to provide the necessary additional equations.

As a preliminary example let me take my solution to the problem of extrusion* (1945), treating it on a plane-strain basis as Siebel does, and supposing also that work-hardening can be neglected. This, so far as I know, is the first steady-state problem to have been solved by applying the above principle. Consider, to begin with, direct extrusion (Fig. A (*a*)), and suppose the friction on the chamber walls to be so great that 'sticking' occurs, so that one pair of bounding slip-lines meets the side walls tangentially. The slip-lines in regions ADE, $A'D'E$ are straight lines through the die-corners A and A', and concentric circular arcs. Regions $DEFC$, $D'EFC'$, are the unique continuation from the circular arcs DE, $D'E$. These regions have to be calculated numerically. Within $ABCD$, $A'B'C'D'$ is the 'dead-metal' which is trapped in the corners during the initial stage of the extrusion, and remains there during the steady-state flow. This slip-line field is the correct one because it can be shown that uniformly streaming material, which enters it across CFC' and then undergoes a complex distortion while passing through the plastic region, is again converted by the time it crosses AEA' into uniformly streaming material leaving the die. None of the other possible slip-line fields satisfying the stress boundary conditions would have this property. The slip-line field for inverted extrusion is shown in Fig. A (*b*); this would also represent direct extrusion with perfectly lubricated walls. The various regions of the slip-line field are similar in type to those already described. The dead-metal is now less in extent. General qualitative agreement with experiment, as regards

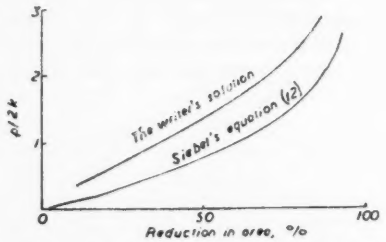

FIG. B—Relation between ram pressure and reduction in area, for inverted extrusion

the extent and shape of the plastic region, can be seen from illustrations given by Pearson[5] in his book "The Extrusion of Metals." It is also possible to calculate the distortion of a square grid ruled on the material; the familiar severe shearing and dragging back of the surface layers is closely reproduced. Figure B shows the relation

* This, and some of the other work of mine mentioned here, has been described in papers for the Armament Research Department.

between the calculated extrusion pressure p (*i.e.*, load divided by ram area) and the percentage reduction in area, for inverted extrusion. The pressure ordinate is divided by the two-dimensional yield stress $2K$, corresponding to the mean speed and temperature of extrusion. Also shown for comparison is Siebel's equation (12). The latter corresponds to plastic work expended in reducing the diameter by uniform extension. The difference between the two curves corresponds to additional work expended in internal shearing due to the complicated process of distortion which actually occurs. Siebel also gives another relation for the extrusion pressure (equation 13) which is obviously empirical ; unfortunately he does not define his symbol α, so that numerical comparison is not possible. It should be mentioned that the slip-line fields in Fig. A apply only for certain ranges of the reduction in area ; the solutions outside these ranges are somewhat different. This cannot, however, be described here. Half of a typical slip-line field for a smooth conical die is shown in Fig. C (which is diagrammatic only) ; this will give some idea of what can be expected in more complex problems.

Consider next the piercing process. When the punch and the chamber walls are smooth this is analogous (in plane-strain) to inverted extrusion. The slip-line field for a flat punch is shown in Fig. D. A false head of dead metal is attached to the punch. The solution is identical with that for inverted extrusion with the same reduction of diameter. The centre-line in Fig. D corresponds to a wall in Fig. A (*b*), and *vice versa*. The relation between the calculated punch pressure p and the reduction in area of the metal is shown in Fig. E. This refers of course to the steady-state pressure and not to the initial pressure required to begin piercing. The existence of a minimum is confirmed by experimental data given by Siebel and Fangmeier[4] (1931). The theoretical

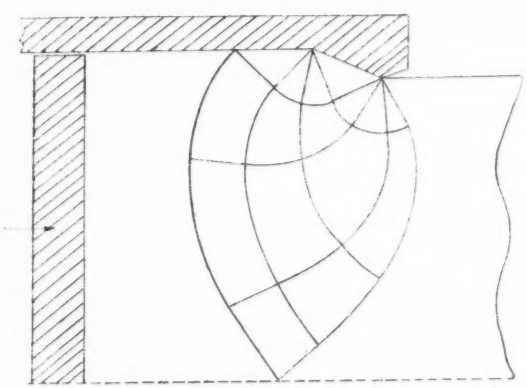

FIG. C—Half of slip-line field for extrusion through a conical die

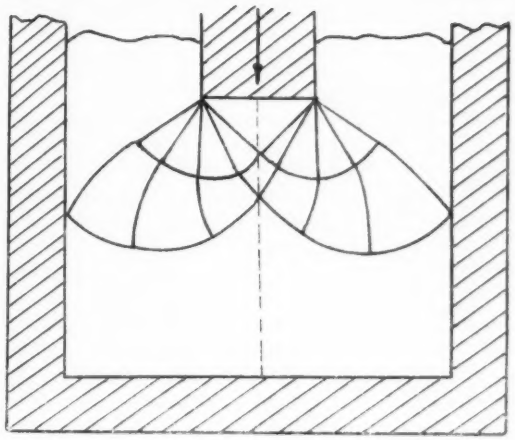

FIG. D—Slip-line field in piercing with flat smooth punch

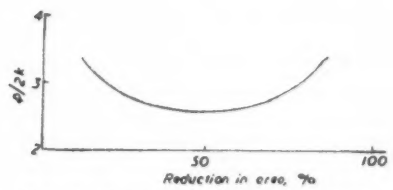

FIG. E—Relation between punch pressure and reduction in area, in piercing with flat punch

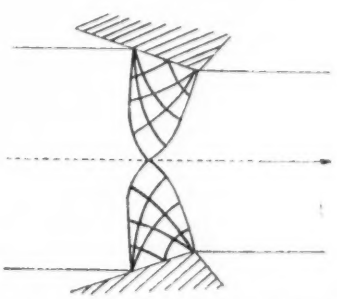

FIG. F—Slip-line field in wire-drawing through a smooth die

minimum pressure has the value $2K(1 + \frac{1}{2}\pi)$. When the punch width is very small compared with the chamber width the material can no longer be assumed incompressible. Elastic strains cannot be neglected, the plastic region is no longer bounded by slip-lines, and the punch pressure tends to the value for deep-punching in a semi-infinite medium. At the other extreme, as the punch width becomes nearly equal to the chamber width, the pressure required for piercing increases without limit. When the walls are rough the above solution has to be modified.

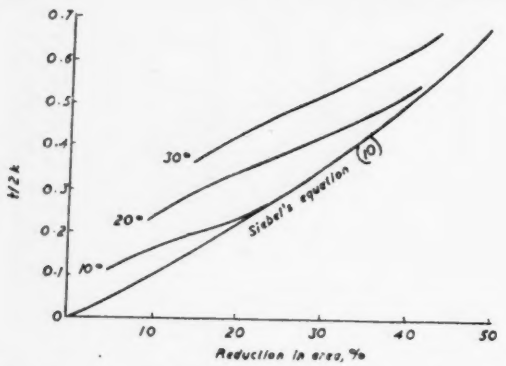

FIG. G—Drawing stress in wire-drawing through smooth dies of various angles

A typical slip-line for wire-drawing is shown in Fig. F. For present purposes the die is supposed smooth and work-hardening is neglected. Both these factors have been taken into account in my full solution. The various regions in Fig. F are of the same type as before ; the geometrical details would take too long to describe here. This slip-line system is the correct one because it converts the rigid-body motion of the material entering the die into rigid-body motion of the drawn material. It is instructive to compare the calculated mean drawing stress (*i.e.*, load divided by final area of wire) with that given by Siebel in equation (10). The drawing stress t is shown in Fig. G as a function of reduction of area for die half-angles of 10°, 20°, and 30°. For the same reduction the stress increases with increasing angle owing to the increased expenditure of 'non-useful' work in distortion which does not contribute to the reduction in area. Siebel's equation (10) corresponds to work expended in uniform extension. It will be seen that, for a given angle, the relative expenditure of non-useful work is far larger when the reduction is small. The calculations represented in Fig. G agree closely with Linicus and Sachs' experiments (1931). For sufficiently severe reductions the curve for each die-angle approaches Siebel's curve. Under these conditions the stress calculated from a slip-line system *not* satisfying the velocity boundary-conditions is a good approximation to the correct value. This is probably because the various possible slip-line systems which satisfy the stress boundary conditions do not differ, on the whole, much from each other. By analogy it can be supposed that in sheet rolling, where the arc of contact is large compared with the mean thickness of the stock, current theories (which do not consider either the shape of the plastic region or the velocity solution) may be fairly near the truth. When, however, the arc of contact is small compared with the stock thickness, then the current theories are likely to be seriously in error. This has been remarked by Dr. Orowan in his note at the end of Special Report No. 34. This point will be returned to in connection with die-forging, or peening, which I will consider next.

In die-forging, a block of metal is thinned in one direction and correspondingly extended in another by pressing it at various points between two dies. True forging begins, therefore, when the load on the dies is such as to cause the plastic region just to spread right across the block. The slip-line field at this moment is shown in Fig. H for smooth flat dies. This is in qualitative agreement with that given by Siebel, and apparently suggested to him by observations of Lüders' lines. This solution was given first by Prandtl (1923)

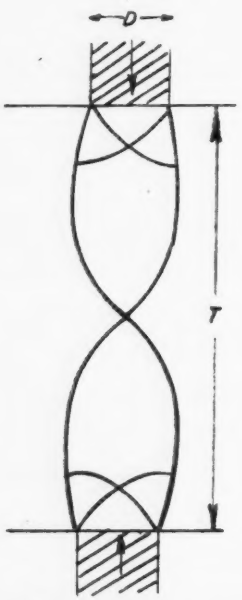

FIG. H—Die-forging

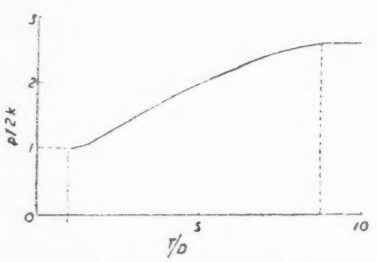

FIG. J—Die pressure in forging

in a similar punching problem, without, however, showing why it happens to be the correct slip-line field. This can be proved by showing that there is a velocity solution corresponding to this field, compatible with the downward motion of the rigid dies and the lateral motion of the rigid material bordering on the plastic region. Figure J gives the relation between the calculated die pressure p and the ratio T/D, where T is the block thickness and D is the die width. When $T/D = 1$, p is equal to $2K$, the compressive yield stress in plane strain. As T/D increases, p increases owing to the constraint of the rigid metal at the sides, finally reaching a maximum value of $2K(1 + \frac{1}{2}\pi)$ when $T/D = 8{\cdot}75$. In the centre of the block there is a tensile stress acting perpendicularly to the line joining the dies. This has a maximum value of about $1{\cdot}1 \times 2K$ when $T/D = 8{\cdot}75$. For larger values of T/D the metal flows out round the dies at the surface, just as in a hardness test, before the plastic region has spread right across the block. This is similar to what happens in wire-drawing and ironing where the pressure on the die increases with decreasing reduction of area, until eventually the metal bulges in front of the die at very small reductions. We see, too, that in rolling, as Dr. Orowan has remarked, the roll pressure is likely to exceed the compressive yield stress by a factor of two or three whenever the arc of contact is small compared with the stock thickness. This is quite apart from the effects of friction or of work-hardening, and is due to the constraint of the rigid metal at either side of the roll gap.

It should be clear, even from this brief description, that an engineer can learn much from an idealized solution based on a plane-strain model. He can gain not only a qualitative, but also, in my experience, a close quantitative insight into the stresses and strains in forming processes. This is particularly fortunate since correct solutions to general axially-symmetric problems in plasticity are not yet feasible, even in principle. Even when the solution can finally be seen in principle, it is safe to say that the labour of numerical computation will often be prohibitive. For this reason, too, engineers would do well not to be put off by the obvious criticism of plane-strain solutions to axially symmetric problems, and, while bearing in mind the limitations of such solutions, should extract all that is useful from them.

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Dr. **E. H. Lee** (Directorate of Atomic Energy, Risley, near Warrington) : I should like to discuss the theoretical aspect of this work, because a sound theory is necessary for a full interpretation of these problems, as has been shown by Mr. Hill. What I shall say will reiterate to a great extent what Mr. Hill has said, but I think that the points which he was making are of sufficient importance to bear emphasis.

The work which we started at Fort Halstead during the war has shown the need for looking into the deformation problem in considering plastic-flow solutions. It is most unusual for a particular plastic problem to require the plastic flow in a certain region for which the stresses are given on the boundary, these stresses being so chosen that the whole field is in plastic flow ; in most practical problems the plastic flow is determined by velocity values on the boundaries, and in this case it is necessary to solve the velocity problem to get the solution. In addition, one does not know in general that the whole field is plastic, and one has to use the velocity solution on the plastic–elastic boundary to determine the complete solution of the problem with the elastic boundary determined.

Siebel mentions in his paper that in general quite a number of problems can be solved in terms of the boundary stress only, but I think that the difficulty which he runs into in this assumption is clearly shown by the case discussed by Mr. Hill, shown in Fig. 14 of Siebel's paper, in which he is considering the problem of extrusion. The fact that he has not looked into the deformations means that he cannot choose between the three examples which he gives. In (*a*) he just ends the plastic field on a more or less arbitrary boundary, and that boundary can be determined only by doing a full stress and velocity solution and choosing the boundary so that the two fit together.

In the same way, in his treatment of the problem of crushing a plastic material between two surfaces—the first problem which he discusses —he has the same difficulty, and, for example, in Fig. 5 he gives a solution which does not in fact solve the problem which he has set out to solve ; the problem of the plastic flow field in a plastic material pressed between rough plates so that there is the full sticking friction at the surface of the plate. That is in fact solved by a system consisting of radial lines shown in Fig. K, where all along the surface the full shearing stress

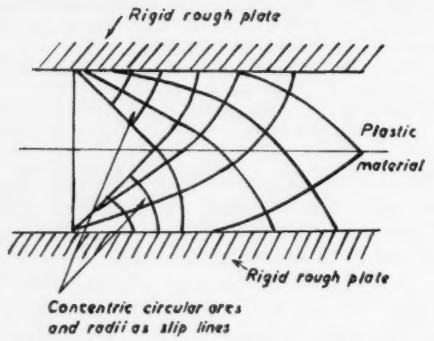


FIG. K—Stress lines on crushing a plastic material between two rough plates

obtains. The rather complicated solution which Siebel gives does not solve this problem, and, because he is considering a stress field only, he cannot deduce the fact that the specimen actually bulges out, as he says in discussing Fig. 5.

The same development is important in rolling problems. This was mentioned by Dr. Orowan in his paper to the Institution of Mechanical Engineers. In the case of rolling problems, however, the boundary conditions are more complicated. In most of the other metal-forming problems, as, for instance, drawing, there is a fixed rigid boundary and a steady state, but in the case of rolling the boundary condition is not a uniform motion but a rotary motion, so that we have not the simple condition regarding uniform velocities at the boundary of the plastic region.

It would be important to find a complete solution for the rolling problem determining the actual shape of the friction hill when these points are taken into account. For instance, in the first part of the discussion on Special Report No. 34, reference was made to the problem of the neutral point. In fact there cannot be an actual neutral point, because if we have material being squeezed out in the two directions indicated in Fig. L, and friction occurs leading to a shear stress in the material, the shear stresses would be incompatible at this point, because the shear stress on the one surface must be the same as the complementary shear component on the perpendicular surface for equilibrium, and this incompatibility leads to the formation of a rigid region which actually evens out the friction hill. This point was mentioned by Dr. Orowan. It requires a complete solution which ties up the velocity solution with the stress solution in order completely to determine the form of the friction hill.

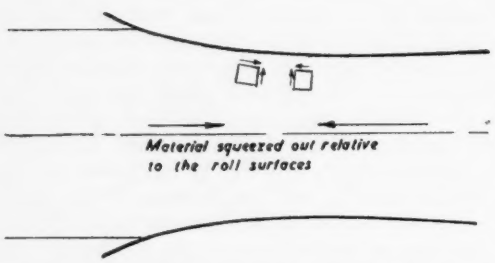


FIG. L—Shear stress developed on rolling

There is one point which Dr. Maccoll mentioned to which I should like to refer, and that is the rôle of elastic stresses in this work. In the problems which we have been considering today, the material is in general free to flow with fairly large values of strain, very much larger than elastic strain, which is of the order of 1 in 1000, so that in these cases it is permissible to neglect elastic strains and to assume the elastic part to be rigid. For example, at a boundary between elastic and plastic regions it is permissible to consider the elastic material as rigid, and this will not affect the plastic solution as long as the boundary is free to allow large deformation to take place. In such cases we can use the simplified plastic theory in which we neglect the elastic stresses and use the Hencky equations.

If, however, we have a thick cylinder with internal pressure, as the internal pressure increases plasticity starts on the inside and we have a plastic region surrounded by an elastic region. For long cylinders with no flow parallel to the axis the plastic strains cannot be large compared with the elastic since the whole plastic region is included in the elastic boundary, so that we cannot use the theory which neglects the elastic strains compared with the plastic strains. In this case the equations of plasticity become much more difficult, but for certain simple problems they can be solved. We did in fact treat the thick tube problem in some work done at Fort Halstead during the war. With a simple strain distribution one can develop the complete theory, and the effect of taking into account the elastic part of the deformation in the plastic region does modify the usual theory of the plastic flow in thick tubes, in which one assumes the usual slip lines and neglects the effect of the elastic strains there. I think that this may be an important point in some problems, but, fortunately, in most metal-forming problems where we are considering large deformations the question does not arise, and it is permissible to neglect the elastic strains.

Professor **E. Orowan**, F.R.S. (Cavendish Laboratory, Cambridge): The papers presented today and the contributions to the discussion give a vivid picture of the important change that has

taken place in the treatment of plastic deformation and plastic working in recent years. Dr. Siebel's paper is an authoritative account of the classical period which began about 1923 with the papers of Hencky and Prandtl and ended when the war began ; Mr. Hill, Dr. Lee, and Dr. Maccoll, on the other hand, have described the change that has taken place since. In the period between the two wars, it was believed that in two-dimensional plastic problems the stress distribution could be obtained without any knowledge of the strains. This belief arose when Hencky pointed out that the number of stress components in the two-dimensional problem was equal to the number of equations available for their determination. The snag is that two of the equations, those representing the equilibrium conditions, are differential equations, and the boundary conditions cannot be determined, in general, without some knowledge of the deformations. Mr. Hill and Dr. Lee have played leading rôles among those who recognized the importance of this point and inaugurated a momentous change in the treatment of plastic stress and strain distribution problems.

Similar and almost simultaneous changes have taken place in the theoretical treatment of rolling. The development of rolling theory falls into three clearly separated periods ; the first period ended with the appearance of Dr. Siebel's paper on the subject in 1924, the second lasted from 1924 until a year or two ago, and the third has only just begun. In the first period, it was believed that the pressure between the rolls and the rolled stock was equal to the compressive yield stress or only a little higher ; it was not realized that the mean pressure may rise to values several times higher if the friction is high and the rolled material is thin relative to the diameter of the rolls. In the second period from 1924 onwards, the influence of friction upon the roll pressure was clearly seen and more or less accurately calculated. This influence is due to the fact that, as the rolled stock is compressed between the rolls, it spreads in the plane perpendicular to the direction of compression, and this is opposed by the friction at the roll surfaces. In addition to the pressure needed for compressing the material without friction, therefore, an additional pressure is needed for squeezing it out of the roll gap against the frictional resistance of the rolls.

The third period can be said to have begun quite recently with the realization that there are two more factors that may raise the roll force considerably above the value calculated from the yield stress of the material and the frictional resistance of the rolls. The first factor is the presence of purely elastic areas between the rolled stock and the rolls, particularly at the plane of exit ; the force acting upon the stock in these areas must be added to that in the areas of plastic deformation to which the classical calculations of roll pressure refer. The elastic roll force may be quite considerable ; in an extreme case of practical importance it may be responsible for the whole roll force. It is well known that a strip cannot be reduced beyond a certain limit with rolls of a given diameter ; when a limiting strip thickness is approached, the roll faces recede elastically by the amount of the strip thickness and no further plastic deformation takes place. In this case the entire roll force, which may be very high, is of purely elastic origin.

The second factor to be added to the frictional one is the non-uniformity of plastic deformation. The pressure needed for deforming a plastic body is equal to the yield stress only if the pressure is not concentrated on a part only of a face of the body ; if it is, the undeformed parts exert a constraint upon the deformed region and raise the pressure needed for plastic deformation. Thus, if a plane circular punch is pressed into a large plane face of a plastic body, the mean pressure is about 2·8 times the yield stress if the material is ideally plastic ; if the cross-section of the punch is a long narrow strip, the mean pressure is, according to Prantdl, $(1 + \frac{1}{2}\pi) = 2{\cdot}57$ times the yield stress. The operation of pressing a narrow compression tool into an extended plastic body may be called ' peening '; obviously, a pronounced peening effect is bound to occur in ingot rolling where the length of the area of contact is often very much less than the thickness of the rolled stock. Until recently, it was assumed that the mean pressure in such cases, where friction is insignificant, is approximately equal to the yield stress ; owing to the gross inhomogeneity of plastic deformation, however, it may be very much higher. In extreme cases, the mean pressure in ingot rolling must be expected to be up to 2·5 times higher than the yield stress, quite apart from frictional and elastic effects.

Mr. **G. M. Brown** : The paper by Dr. Siebel will be helpful and valuable to engineers engaged in the design and operation of machines for the plastic shaping of metals, by pressing, drawing, and rolling, taking into account as it does the effects of friction between the metal under treatment and the tools used.

His Figs. 2 and 3 are of particular importance in connection with rolling, the first being applicable where there is no slip between the rolls and the metal, and the second in cold rolling where slip between the rolls and the material going through the roll gap occurs over nearly the whole arc of contact.

They, together with Fig. 4, indicate the possibility of tracing the stream lines and wave fronts

of the material going through a pair of rolls and the genesis of the curves obtained by Hollenberg and more recently by Orowan as shown in his recent paper[1]—always provided that the magnitude of the frictional drag along the arc of contact is known, or can be estimated with reasonable accuracy, and at present this is not possible.

Some twenty years ago a theory of rolling was developed by Ekelund[2] based on the assumptions that rolling is simply a process of homogeneous compression and that there is slip between the metal and the rolls everywhere along the arc of contact except at the neutral point and against a coefficient of friction of constant magnitude which changes sign instantaneously at the neutral point—a true example of the ideal finita discontinuity of mathematicians.

This question of friction is a very important one in rolling and it is astonishing that every writer on rolling, up to the present time, has been content to assume without question that it is actually constant in magnitude and does really change sign suddenly at the neutral point. The result of this assumption is clearly shown in curves of rolling pressure calculated either by Ekelund's method, which does not take into account the shearing stresses, or even by Orowan's method, which does, *i.e.*, there is a very sharp and pronounced peak at the neutral point. It is evident that neither of these things can occur and Dr. Siebel and his daughter, Dr. Lueg, have given no actual curves of rolling pressure in none of which is there any sign of either of these phenomena : the peaks of their experimental curves are all well rounded and in fact much more rounded than can be accounted for by the small width of the pressure pin used to record them. These curves, the only curves of the kind available at present, should be corrected for the finite width of the pressure pin, but the writer has not found any easy or satisfactory way of making it, and is of the opinion that any error made by omitting such correction is of minor importance and does not materially affect the value of the information to be got by examining them.

Figure M is an approximate representation of such a curve of rolling pressure. N is the neutral point and ANA shows the variation along the arc of contact of the frictional drag between the rolls and the material between them ; it passes through zero at the neutral point where the rolls and the rolled material have the same speed and there is no slip, and builds up gradually till it becomes sufficiently great to produce slip near the points AA. At N, the speed of the material is probably uniform across the section but at AA and elsewhere it is not, as is clearly indicated by the experimental curves of Hollenberg and Orowan. On account of imperfect plasticity and

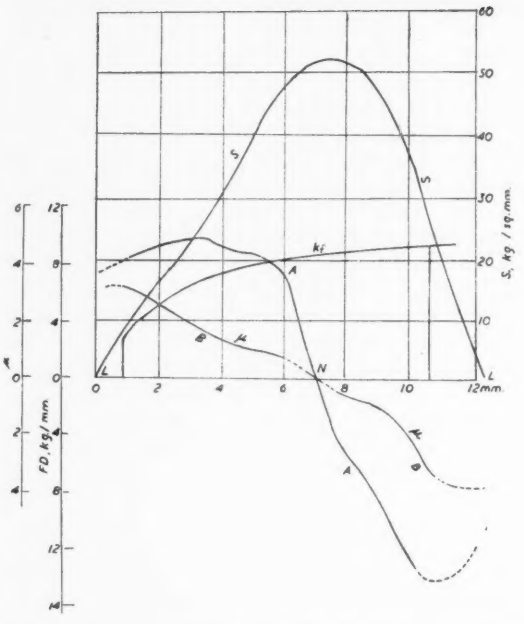


FIG. M—Approximate representation of rolling-pressure curve

possible slight variations of the incipient slip the positions of AA are rather indefinite and it is not easy to determine where slip actually begins. The curve BNB is the result of dividing the frictional drag by twice the rolling pressure S and where slip occurs represents the coefficient of friction. The length of the arc of contact LL is generally calculated on the assumption that the rolls are absolutely rigid and the rolled material plastic and non-elastic by the formula $L = RS$ where R is the radius of the rolls and S the reduction of the thickness of the material. In cold rolling neither assumption is correct and in the cold rolling of these hard materials L may actually be two or more times the calculated value. Rolling pressures calculated on this basis will therefore be much greater than the actual pressures required or used and should be of use in practice only for rolls of similar size performing similar operations on the material. Hitchcock has developed a method of calculating L which may be used in such cases but no generally accurate method of dealing with this problem has yet been devised which can be used for practical work, and long and tedious arithmetical methods are the only ones available at present if accuracy is desired : a drawback which seems incidental to most cold-rolling calculations.

References

1. E. OROWAN : *Proceedings of the Institution of Mechanical Engineers*, 1943, vol. 150, p. 140.

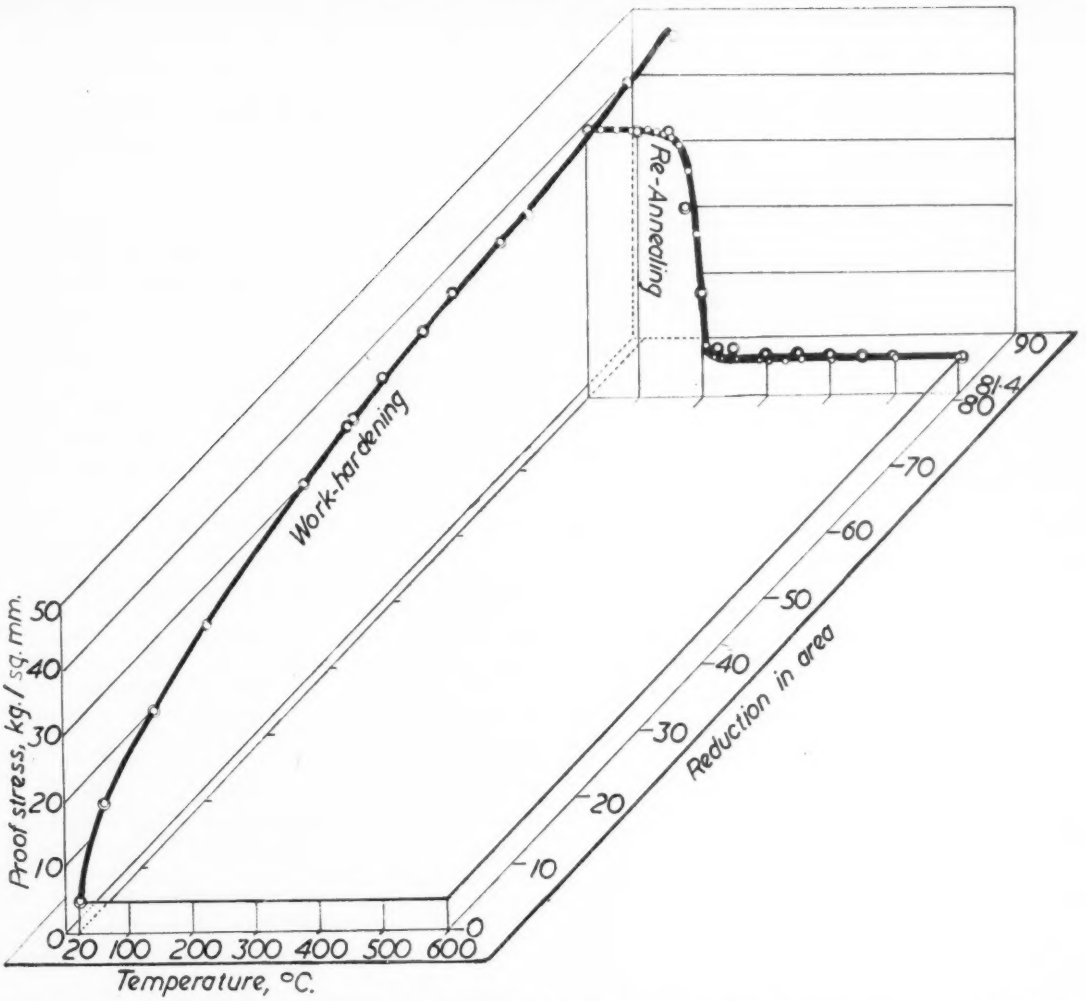


FIG. N—0·1% Proof stress of copper as a function of reduction in area z resulting from cold-drawing and re-annealing curve for copper with 81·4% reduction. Circles show theoretical points, double circles show experimental points. Time of annealing, 0·5 hr.

2. S. EKELUND : *Jernkontoret Annaler*. 1927, vol. III, p. 39, vol. 112, p. 67 ; (translation) *Steel*, 1933, vol. 93.
3. E. SIEBEL and W. LUEG : *Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenförschung*, 1933, p. 1.

Dr. Ing. **M. Balicki** (Polish University College, London) : In connection with the question Dr. Desch has just mentioned, namely, that of the need for a strict theory of hot-rolling and hot-deformation, I should like to draw attention to some work which might be useful in attacking this important problem. The results on work-hardening and re-annealing recorded by Professor Krupkowski and myself might be directly utilized for the purpose, because, as Dr. Desch has just pointed out, these phenomena jointly appear in the process of hot-deformation. In fact, this feature was one of the reasons why we started to 'sort out' and make a systematic approach to work-hardening in general and devoted so much attention to the study of re-annealing, using a variety of physical-testing methods. There is a similarity between all forms of deformation, and Dr. Siebel's paper very clearly brings this up. Being aware of this similarity we decided to concentrate on cold wire-drawing as an easily controlled method of deformation, supplying in addition the hardened metal in a form very convenient for testing. Our approach was to plot the values of a property against the percentage reduction in area, z, which was accepted as the measure of degree of work-hardening. Thus the familiar work-hardening curves have been obtained

for a number of properties and for copper, nickel, and iron. From an analysis of such curves a great deal may be learned about how work-hardening takes place in metals. These curves, as may be seen from the Fig. N, form a basis for subsequent re-annealing curves.

For the question of hot-rolling or any other hot-deformation, which should be considered as an instantaneous deformation to a degree of reduction in area plus superimposed re-annealing, it is of the greatest importance to know something about the rules which govern the rate of re-annealing, *viz.*, recrystallization. The quantitative examination which we made was fairly successful and it is now possible to calculate recrystallization curves which, while still approximate, follow the experimental data quite closely. This may be seen in the Figure, where the experimental points are shown as circles or as double circles. It would seem that this treatment should be sufficiently accurate for the purposes of scientists interested in a quantitative approach to hot-rolling and hot-deformation.

The curve work-hardening against reduction has not been calculated as yet, but some attack on this problem also may be forthcoming. In my opinion this calls for more experimental and theoretical work along the lines which we started and which we tried to carry on with the humble means at our disposal.

I should like to take this opportunity of expressing my thanks to the President and the Council of the Iron and Steel Institute and also to University College, Swansea, for showing so much understanding towards the idea and for enabling me to do a piece of work in this country. I am also very grateful to the Council and the President for awarding this research the Carnegie Silver Medal.

The **President** (Dr. C. H. Desch, F.R.S.): In view of what Dr. Balicki has said, we have to remember that there are three different stages in the study of a rolling process. First, you can deal with an ideally plastic material, as if you were rolling plasticine ; then you have the problem of a material which work-hardens, and with hot rolling you have to deal with a material which work-hardens and recrystallizes. That makes the problem of hot rolling more complicated than that of cold rolling.

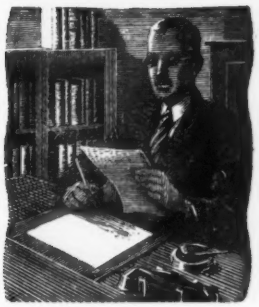
In conclusion the President said: This has been a very interesting discussion. I think it will be realized that the Rolling Mill Committee has a very important job of work to do, which it is carrying out very well. I should like to emphasize what Dr. Ford has said about our indebtedness to the manufacturers and others who have helped. Research of this kind is naturally rather costly, but we have had much co-operation in the provision of apparatus, and, what is also very important, the provision of suitable material.

Correspondence on the papers presented at the Meeting will be published in the September issue of the *Journal*, as follows :

From W. Stafford, P. F. Wyatt and R. C. Chirnside on the paper "A New Scheme for the Microchemical Analysis of Ferrous Alloys " — from W. J. Todd, D. Knowles and Dr. Schofield on the papers "A Photographic Investigation of the Brightness Temperatures of Liquid Steel Streams " and "A Symposium on the Contamination of Platinum Thermocouples " — from J. E. de Graaf, Dr. J. H. Chesters and M. W. Thring on the papers " The Operation of Open-Hearth-Furnaces with Coke-Oven Gas " and "An Experimental Furnace for the Investigation of Open-Hearth-Furnace Combustion Problems " — from Dr. P. Vajragupta on the paper "Application of Slag Control and an Investigation of Basic Open-Hearth-Furnace Slags " — and from G. E. Tanner and J. S. Caswell on the " First Report of the Rolling-Mill Research Sub-Committee " and the papers " Fluctuations of the Distribution of Torque between Rolling-Mill Spindles " and " The Application to Shaping Processes of Hencky's Laws of Equilibrium."

The Discussion on the Symposium on Hardenability will also be published in the September *Journal*.

CORRESPONDENCE



LETTERS TO THE EDITOR · GENERAL CORRESPONDENCE

Supply of Publications

16*th May*, 1947.

The Secretary,
The Iron and Steel Institute.

Sir,

During April the Institute published a substantial and valuable symposium on "The Hardenability of Steel," and will publish another symposium on "Powder Metallurgy" in the future. But members do not receive these symposia without paying ten shillings each over and above their subscriptions, although, to research metallurgists at least, they include some of the most interesting and important material published by the Institute in recent years. Since the new-style *Journal* to which our subscriptions entitle us has a rather small amount of space devoted to research topics, the present position is that "research" members of the Institute largely receive material they are only indirectly interested in for their subscription, and have to pay extra fees to obtain material in which they are directly interested. We think this situation should be so adjusted that members receive the material that mainly interests them without having to make extra payments. It may, for example, be possible to publish future symposia in the *Journal*, or to issue them in place of the normal *Journal* one month, or to issue two *Journals* each month, one containing all the "research" papers in full, and abstracts of "production" papers, and the other containing the "production" papers in full and abstracts of the "research" papers, both containing the material such as abstracts common to all members, and members subscribing to one or the other or to both as they choose.

We hope it will be possible to publish this letter in the *Journal*.

Yours faithfully,

C. J. Leadbeater (Member)
R. Willows (Member)
H. F. Hall (Member)
F. Hargreaves (Associate)
D. Pickman (Member)
D. McClean (Member)
Ashley R. Moss (Member)
C. F. Marks (Member)
L. Northcott (Member)
A. W. Hothersall (Member).

Armament Research Department.

Dr. D. McClean, 26*th June*, 1947.
Armament Research Department.

Sir,

I am directed by the Council to thank you and your colleagues at the Armament Research Department for your letter of 16th May, 1947, and to say that the Council welcomes expressions of opinions by members and hopes that others will follow your example in making suggestions for improving the service provided by the Institute.

The Council regrets that it cannot adopt your proposals both because the cost under present conditions would be prohibitive and because of the restrictions on the supply of paper. Later, should these difficulties be removed, the Council will be prepared to reconsider this decision.

Hitherto a preponderant proportion of the space in the Institute's *Journal* has been given up to papers of metallurgical and "research" interest. It is the intention of the Council that the *Journal* in its new monthly form should cater for the interests of all sections of the Institute's membership. A considerable proportion of the available space will continue to be allocated to metallurgical and "research" papers. Reference to recent issues of the *Journal* will show that this is in fact being done.

Special Reports have in the past frequently been made available to members free of charge. It is hoped to continue this practice. A charge must, however, be made in certain cases, both because the cost of publication is now very high and because a check on the consumption of paper is now essential. The only alternative at present would be for the Institute not to publish these reports. The same considerations prevent the issue of two *Journals* or an increase in the size of the *Journal* by including symposia.

It is perhaps not fully realized how greatly the costs of publication have risen. Reference to the published accounts for last year will make this clear while a further substantial increase in expenditure is anticipated for the current year. This matter is engaging the earnest attention of the Council. Hitherto it has been possible to avoid increasing subscriptions, although several other institutes have been obliged to augment their revenue in this way. The present standard rate of subscription was fixed at £3 3*s*. 0*d*. a year many years ago. Since then, Joint

Members with the Institute of Metals and Institution of Metallurgists and certain societies overseas have been required to pay only £2 12*s.* 6*d.* a year, while Associates up to the age of 28 are admitted at the reduced annual subscription of £1 5*s.* 0*d.* and, in the case of Joint Members of these two Institutes and of the Affiliated Local Societies, £1 1*s.* 0*d.* The Council does not propose to increase subscriptions at the present time, but in view of rising costs, the decreased purchasing power of money, and the increased service provided, this means of augmenting revenue may have to be considered at a later date. It is believed that reference to the publications of other Institutes with comparable subscription rates will show that good value is being obtained by Members.

As requested, this correspondence will be published in the *Journal*.

Yours faithfully,
By order of the Council,
K. HEADLAM-MORLEY,
Secretary.

4, Grosvenor Gardens,
London, S.W.1.

Quenching Media

5th June, 1947.

The Editor.
Sir,

Experience of the Schmidt approximation using the formulæ given in Appendix II of the paper on quenching media by Jones and Pumphrey,* has shown that arithmetical fluctuations may be encountered in the calculated centre temperature for cylinders. It is not always practicable to smooth the fluctuations by "commonsense adjustment," and in some cases these adjustments have to be repeated so often that the final result can become more a matter of guess-work than of mathematics.

The difficulty can be overcome by choosing Δt so that $a^2\Delta t/(\Delta r)^2 = \frac{1}{4}$ instead of $\frac{1}{2}$, in deriving the formula. In this case the formula for T_0 takes on a very simple form which eliminates the fluctuations formerly encountered. The general formula is a little more cumbersome, but as two layers often give sufficient accuracy, the extra labour involved need not be prohibitive.

The derivation of the formulæ is given below for a general case $a^2\Delta t/(\Delta r)^2 =$ constant. Starting from the replacement of differentials by small quantities, as in Appendix II, we have:

$$\frac{T_{n,\,m+1} - T_{n,\,m}}{a^2\Delta t} = \frac{T_{n+1,\,m} - 2T_{n,\,m} + T_{n-1,\,m}}{(\Delta r)^2} + \frac{T_{n+1,\,m} - T_{n-1,\,m}}{2r\,\Delta r}$$

By putting $\frac{a^2\Delta t}{(\Delta r)^2} = c$, $r = n\,\Delta r$

$$T_{n,\,m+1} - T_{n,\,m} = c\,(T_{n+1,\,m} - 2T_{n,\,m} + T_{n-1,\,m}) + \frac{c}{2n}\,(T_{n+1,\,m} - T_{n-1,\,m})$$

$$T_{n,\,m+1} = (1-2c)\,T_{n,\,m} + c\left(1+\frac{1}{2n}\right)T_{n+1,\,m} + c\left(1-\frac{1}{2n}\right)T_{n-1,\,m}$$

$$= (1-2c)\,T_{n,\,m} + c\left(1-\frac{1}{2n}\right)(T_{n-1,\,m} - T_{n+1,\,m}) + 2c\,T_{n+1,\,m} \quad \ldots\ldots\ldots\ldots\ldots(A)$$

For the centre:

$$\frac{T_{0,\,m+1} - T_{0,\,m}}{\Delta t} = \frac{4a^2}{(\Delta r)^2}(T_{1,\,m} - T_{0,\,m})$$

$$\therefore\ T_{0,\,m+1} - T_{0,\,m} = 4c\,(T_{1,\,m} - T_{0,\,m})$$

$$T_{0,\,m+1} = 4c\,T_{1,\,m} - (4c-1)\,T_{0,\,m} \quad \ldots\ldots\ldots\ldots(B)$$

Putting $c = \frac{1}{4}$ in equations (A) and (B), we get:

$$T_{n,\,m+1} = \tfrac{1}{2}\left\{(T_{n,\,m} + T_{n+1,\,m}) + \frac{2n-1}{4n}\,(T_{n-1,\,m} - T_{n+1,\,m})\right\}$$

$$T_{0,\,m+1} = T_{1\,m}$$

Yours faithfully,
(Miss) R. E. W. GUNN.

Brown-Firth Research Laboratories,
Sheffield.

* *Journal of the Iron and Steel Institute*, 1947, vol. 156, May, pp. 37–54.

1st July, 1947.

The Editor.
Sir,

We thank Miss Gunn for her remarks on our paper. The general formula is rather more complicated when the time intervals are chosen so that $a^2\Delta t/(\Delta r)^2 = \frac{1}{4}$ instead of $\frac{1}{2}$, and if n, the number of layers, is large (> 4) considerably more arithmetic will be involved. However, if n is small, the arithmetical fluctuations in the centre temperature become troublesome; the method Miss Gunn suggests is a convenient way of avoiding them.

Yours faithfully,
F. W. JONES,
W. I. PUMPHREY.

Brown-Firth Research Laboratories,
Sheffield.
Metallurgy Department,
University of Birmingham.

Electrolytic Polishing

19th April, 1947.

The Editor.
Sir,

Mr. Merchant is to be congratulated on his contribution* to the study and application of electrolytic polishing.

As he points out, the most difficult problem is the design of a suitable anode connection which must hold the specimen firmly, provide good contact to ensure uniform current-density distribution, and be constructed so that the specimen may be removed from the cell easily and quickly for washing and subsequent treatment.

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, February, pp. 179–194.

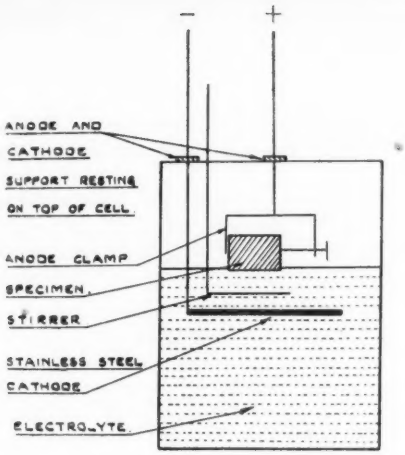


FIG. 1—Apparatus for electrolytic polishing

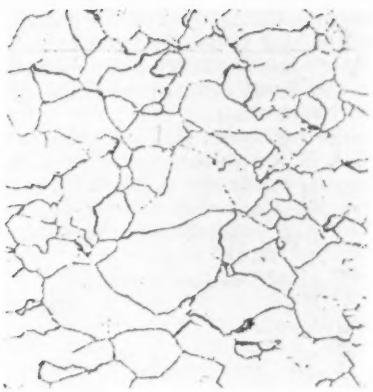


FIG. 5—18/8 Type stainless steel

The author describes four types of anode connection all of which appear rather complicated and involve such precautions as vitreous enamelling and, moreover, since the anode connections are completely immersed in the electrolyte, the contact area gradually polishes away and the clamp must eventually be replaced.

I have found it advantageous to use a simpler method in which the specimen is held in a horizontal position by means of a screw-clamp so that only the surface to be polished is immersed in the electrolyte. This method avoids replacement and insulation of the clamp and only the surface area of the specimen face to be polished need be considered in calculating the current-density per square centimetre. The anode clamp and stainless-steel cathode are supported by means of two strips of non-conducting material resting on top of the glass cell (as shown diagrammatically in Fig. 1), and the specimen can be quickly removed, washed, and dried while still in the clamp simply by unclipping the electrical terminal. The author recommends that the specimen should not be in contact with the electrolyte except when the required potential difference for polishing exists. This precaution has been found unnecessary when using Jacquet's solution and the method used is to fix the specimen in the anode clamp, adjust the clamp so that the surface of the specimen is just immersed in the electrolyte, switch on to the appropriate current-density for the desired time, then switch off, unclip the terminal, and wash the specimen before removing it from the screw-clamp ready for etching and subsequent microscopic examination. This method gives satisfactory results using Jacquet's perchloric-acid/acetic-anhydride electrolyte, although a higher current-density than that recommended by the author has been found suitable.

Using the anode clamp so that the specimen surface is just immersed in the electrolyte, the optimum conditions were found to be 0·4 amp./sq. cm. for

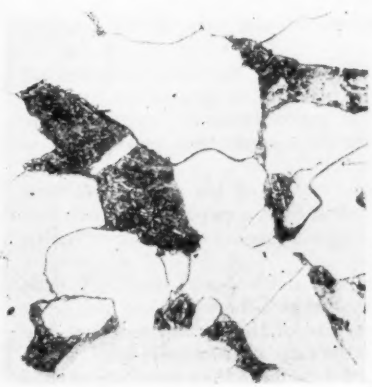


FIG. 2—0·2% Carbon steel. Annealed. Etched in 2% nital

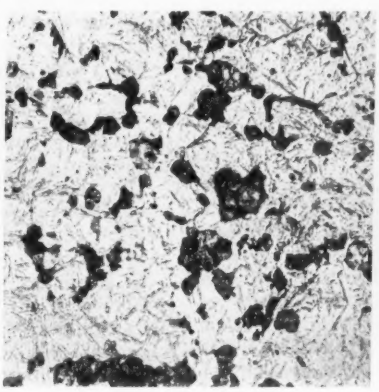


FIG. 3—0·6% Carbon steel. Oil-quenched. Etched in 2% nital

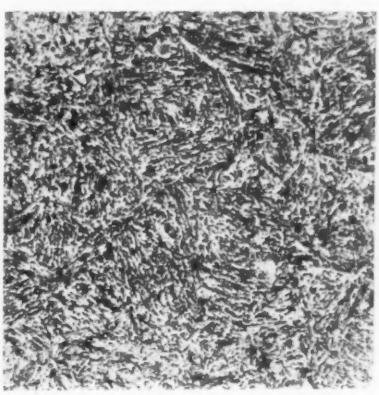


FIG. 4—0·4% Carbon steel. Water-quenched and tempered. Etched in 2% nital

FIGS. 2 to 5—Specimens polished under the following conditions : 0·4 amp./sq. cm. for 2 min. in Jacquet's solution. × 250. (Reduced to nine-tenths linear in reproduction)

2 min. with an anode-to-cathode distance of 2·5 cm. with specimens having a 00 emery finish. I agree with Mr. Merchant in that best results are obtained with Jacquet's solution at temperatures under 25° C. and have also found agitation of the electrolyte by stirring to be essential.

Experience has shown that a wide range of steels, irrespective of heat-treatment, polish satisfactorily under the same conditions, as illustrated in Figs. 2–5.

I regret that I have not had the opportunity of testing the other electrolytes recommended by the author.

Yours faithfully,

JAMES POW.

Messrs. Colvilles, Ltd.,
Motherwell.

The Editor. *5th May*, 1947.

Sir,

I have noted with interest Mr. Pow's contribution and particularly the very clear micrographs attached. It is admitted that with the first two types of polishing head devised by myself (the screw-clip type and the horizontal-platform type), the contact area gradually polishes away, but a magnet-type polishing head, which is simple to make and which enables only the surface to be polished to be immersed, was also described.

I note that Mr. Pow has not found it necessary with Jacquet's solution to avoid contact of the specimen with the electrolyte when the potential difference for polishing does not exist, but when using other electrolytes, particularly those based on nitric acid and those with a higher free-water content, it was found that this condition was essential.

The use of Jacquet's solution at a higher current-density and for a shorter time with the excellent results obtained is also noted ; owing to the relatively very low conductivity of this electrolyte and the limited voltage at my disposal (50 V.) when the work was carried out, this current-density region with Jacquet's solution could not be explored.

Yours faithfully,

H. J. MERCHANT.

Stourport-on-Severn,
Worcs.

Determination of Reactive Oxygen

The Editor. *26th February*, 1947.

Sir,

It is encouraging to see that problems connected with the physical chemistry of steelmaking have been taken up for discussion by the Ingot Committee. With some knowledge of the very valuable research work on steelmaking done by the Committee during the last few years, *e.g.*, concerning solidification of rimming steel, temperature measurement on liquid steel, and determination of gases in steel, one has reason to look forward with great interest to the results of further work on the physical chemistry of steelmaking to be done by the Ingot Committee.

In his paper* Mr. Mackenzie has used Schenck's theory of the carbon reaction as a basis for his conclusions.

The reaction between carbon and oxygen in liquid steel :

$$C \text{ (in liquid Fe)} + O \text{ (in liquid Fe)} = CO \text{ (gas)} \ldots (1)$$

can be looked upon as built up of three different processes :

(1) The atoms of carbon and oxygen dissolved in liquid steel are reacting with one another to form carbon monoxide. To begin with the carbon monoxide formed dissolves in the liquid steel (to a very low content).

(2) The dissolved carbon monoxide is forming gas bubbles escaping from the steel bath.

(3) The atoms of carbon and oxygen used up in process (1) are replaced by other atoms transported to the reaction spot by stirring or by diffusion.

It is the slowest one of the three processes mentioned which determines the rate of the carbon reaction.

Process (1) is of the same kind as the reaction occurring when, for instance, silicon is added to a steel bath containing oxygen. Thereby the following reaction takes place :

$$Si \text{ (in liquid Fe)} + 2O \text{ (in liquid Fe)} = SiO_2 \text{ (slag)} \ldots (2)$$

It is well known that this reaction occurs very rapidly. It is therefore probable that process (1) occurs rapidly as well.

Carbon monoxide would not escape from the steel bath in an open-hearth furnace, process (2), unless gas bubbles be formed. At the formation of a carbon monoxide bubble a considerable pressure has to be overcome owing to the surface tension. If conditions for the formation of gas bubbles are unfavourable no boiling occurs. Process (2) therefore in most cases is characterized by an appreciable inertia. If the concentrations of [C] and [O] alone were determining the driving force of the carbon reaction, carbon monoxide bubbles would be able to form anywhere in the steel bath. This seems not to be the case ; the bubbles are formed mainly where the steel bath is in contact with the porosities of the bottom. For this reason process (2) is the slowest of the three processes and determines the rate of the carbon reaction (1).

When the bath is boiling the transportation of " new " atoms of carbon and oxygen to the reaction spot, process (3), is probably rather rapid. It is therefore reasonable to assume that process (3) is faster than process (2).

The views on the nature of the carbon reaction quoted above are taken from a paper by Körber and Oelsen* who base their statements on rather extensive experiments.

In a review of Schenck's book, Kalling† calls attention to the fact that Schenck, when deducing his formula for the rate of the carbon reaction, has taken into account the rate of process (1) only. Since this process does not determine the rate of the carbon reaction, Schenck's formula is not reliable.

On a few heats made in a basic open-hearth furnace

* *Journal of the Iron and Steel Institute*, 1946, No. II, pp. 55P–59P.

* *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, 1935, vol. 17, pp. 39–61.

† *Jernkontoret Annaler*, 1935, vol. 119, pp. 248–253.

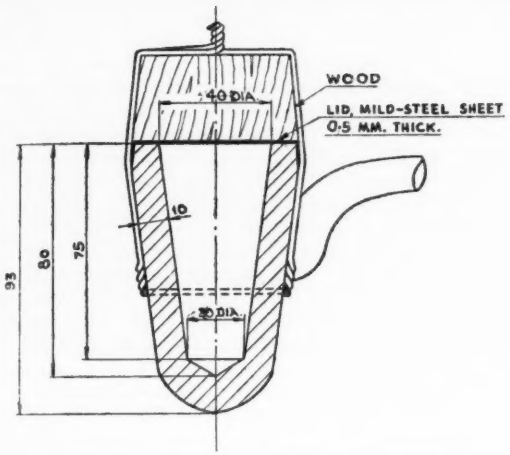


FIG. 1—Section through sampling mould

at Surahammars Bruks, A.B., some steel samples were taken for oxygen determination. The sampling method used was proposed by Mr. N. Rudberg in 1940. The sampling mould, Fig. 1, is made from mild steel. Inside the mould are placed 2 g. of a 1-mm. dia. aluminium wire corresponding to about 0·5% of aluminium in the sample. The mould is furnished with a lid of mild-steel sheet, 0·5 mm. thick. The lid is covered by a conical piece of wood fixed in position by an iron wire of 2 mm. dia. After slagging up to the edge the mould is dipped into the steel bath. When the wire has melted, the piece of wood rises to the slag surface uncovering the slag-free sheet lid. After the lid has melted and the mould has been filled with steel the mould is withdrawn. The samples obtained are free from furnace slag.

The samples were analysed for carbon and oxygen. The oxygen determinations were made by the vacuum-fusion method. The results are shown in Table I. The oxygen contents of two samples taken immediately after each other are in good agreement, which is regarded as a proof that the sampling technique is reliable. The oxygen contents computed

TABLE I—*Results of Analysis*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Heat No.	Sample No.	Time after Melted, min.	[C]	$\frac{d[C]}{dt}$	[O] Calculated	[O] Analysed	$d[C]/dt$ Corresp. to [O] Analysis
A 1075	9	94	0·085	0·0021	0·044	0·038	0·0011
	10	94	0·085			0·037	
A 1078	3	69	0·69	0·0080	0·010	0·013	0·0121
	4	69	0·69			0·013	
	5	103	0·42	0·0071	0·015	0·019	0·0098
	6	103	0·42			0·018	
	7	125	0·28	0·0067	0·022	0·026	0·0081
	8	125	0·27			0·024	
	9	146	0·13	0·0044	0·038	0·031	0·0029
	10	146	0·13			0·033	
A 7738	9	200	0·20	0·0068	0·031	0·022	0·0037
	10	200	0·20			0·024	
	12	224	0·08	0·0013	0·041	0·045	0·0019
	13	224	0·08			0·046	
A 7767	6	143	0·58	0·0108	0·014	0·008	0·0038
	8	169	0·27	0·0091	0·027	0·018	0·0042
	10	190	0·13	0·0042	0·037	0·034	0·0030
	11	190	0·13			0·031	
	13	206	0·09	0·0022	0·042	0·038	0·0015
	14	206	0·09			0·038	
A 9466	5	29	0·24	0·0094	0·032	0·013	0·0009
	6	30	0·24			0·013	
	8	53	0·075	0·0024	0·052	0·046	0·0013
	9	53	0·075			0·043	

by means of Schenck's formula are given in column (6) in the table. These values are not in agreement with the analysed ones. The rates of carbon drop computed by means of Schenck's formula from the oxygen contents analysed are given in column (8). If these values are compared with the actual values of carbon drop shown in column (5) the discrepancies are found to be great.

There seems to be no reason to assume that the steel bath in the open-hearth furnace is containing slag inclusions in suspension during the boil. Steel samples taken by the methods used either by the author or at Surahammar contained slag inclusions, but these formed during solidification of the samples. The oxygen content obtained by vacuum fusion is therefore probably corresponding to the oxygen content dissolved in the liquid steel. The reason why these values are not in agreement with the ones obtained by calculation by means of Schenck's formula might be stated as follows:

Schenck's formula is derived from the assumption that the atomic reaction rate is solely determining the rate of the carbon reaction. No consideration has been paid to the inertia of the carbon reaction caused by the mechanism of the formation of the carbon monoxide bubbles. For this reason the formula should not be regarded as conclusive.

Yours faithfully,

SVEN FORNANDER.

Surahammar,
Sweden.

The Editor. *24th April*, 1947.

Sir,

I thank Mr. Fornander for his interesting contribution.

As this investigation has not provided any direct evidence of the mechanism of the carbon reaction, I have not attempted to define the factors controlling the reaction rate. I agree that one or more of the three processes mentioned by Mr. Fornander may exert a controlling influence. In attempting to find a method of determining the concentration of dissolved oxygen and relating this oxygen content to the concentration of carbon and the rate of boil, no assumption was made as to the mechanism of the reaction. It is reasonable to suppose that the more oxygen present in excess of that required for the oxygen–carbon equilibrium the more vigorous will be the reaction. Even if the area of the gas–metal interface at the hearth retards the evolution of carbon monoxide the rate of evolution will depend on the content of dissolved CO in the metal which is in turn a function of the carbon–oxygen product. There is no indication that the nature of the hearth varies appreciably from one cast to another. The rate of transport of reactants to the hearth will be dependent on their concentrations as well as on the turbulence of the bath which is dependent on the rate of evolution of carbon monoxide. Thus the existence of a formula of the type found is not unexpected on theoretical grounds. From a practical viewpoint, the examination of the origin of the relation is of secondary importance.

Mr. Fornander's failure to obtain correlation between the oxygen content as determined by vacuum fusion and a function of carbon and rate of carbon drop is not unexpected in view of recent work carried out in this country. Speight* has shown that the vacuum-fusion method as normally operated gives low results for oxygen when the aluminium content of the steel is of the order of 1%. For oxygen contents above 0·025% results 30% low have been obtained, probably owing to the absorption of carbon monoxide on the film of volatized aluminium. Microscopic examination of bomb samples when the carbon is high reveals inclusions which were probably present in the liquid steel. The necessity for a good boil to flux out such inclusions is recognized. The vacuum-fusion method does not distinguish between the oxygen from such particles and that dissolved in the metal.

I do not consider that the vacuum-fusion method is satisfactory for determining dissolved oxygen. Where the oxygen content is above 0·025%, values for oxygen given by Mr. Fornander are lower than those calculated from the formula with only one exception. For oxygen contents below 0·025%, all but one of his results are higher than the calculated figures. With sample *A*9466, No. 6, an exceedingly vigorous boil has apparently been maintained by an oxygen content only 0·002% above the equilibrium value. Whatever the mechanism of the carbon reaction, it is axiomatic that an ample supply of oxygen must be available for the rapid elimination of carbon.

Yours faithfully,

I. M. MACKENZIE.

Messrs. Colvilles, Ltd.,
Motherwell.

Reaction between Molten Iron and Hydrogen Sulphide

23rd April, 1947.

The Editor.

Sir,

I would like to congratulate Dr. White and Dr. Skelly on their approach† to a problem which is so obviously fraught with many experimental difficulties.

I am especially interested in the authors' attempt at an explanation of the mysterious grey deposit which they had found on the cooler parts of their furnace tube when the gases hydrogen sulphide and hydrogen had been passed over heated iron specimens. This same deposit has been noted previously in gas-streaming experiments, with which I have been connected, in silica combustion tubes. In these experiments, carried out as part of an investigation into the scaling properties of steels,‡ the gaseous atmosphere was of an oxidizing character in respect of iron and the sulphur addition was in the form of sulphur dioxide. The gas mixture was made up synthetically to contain 80% of nitrogen, 10% of water vapour, and 10% of carbon dioxide, to which

* Communication to Gases and Non-Metallics Sub-Committee, B.I.S.R.A., December, 1946.

† *Journal of the Iron and Steel Institute*, 1947, vol. 155, February, pp. 201–212.

‡ *Ibid.*, 1944, No. I, pp. 253P–273P.

was added during the experiments up to 5% of oxygen and hydrogen respectively, plus small percentages of sulphur dioxide up to 0·20%. The maximum furnace temperature near to the steel specimen was 1150° C., and the deposit was found in a narrow band further along the furnace tube in the direction of the gas flow in a temperature region of perhaps 400–800° C. The grey deposit was difficult to remove except with hydrofluoric acid solutions.

This deposit, like that noted in the authors' experiments, was mainly silica with a small percentage of iron. It formed only when sulphur compounds were present in the furnace atmosphere and it is suspected, although not proved by analysis, that there were slight traces of sulphur in this solid material, as during its removal from the tube with acid a faint characteristic smell of sulphuretted hydrogen was observed.

I have attempted no theory as to the mode of formation or even of the exact composition of the deposit. It is hoped that with the knowledge that this deposit has been found in the presence of oxidizing gases as well as in a hydrogen atmosphere, the authors may be able to arrive at a completely satisfactory explanation.

Yours faithfully,

R. V. RILEY.

Messrs. Bradley and Foster, Ltd.,
Darlaston, Staffs.

8th May, 1947.

The Editor.

Sir,

We wish to express our thanks to Dr. Riley for his interesting comments, which, together with the recent "Symposium on the Contamination of Platinum Thermocouples" by the Liquid Steel Temperature Sub-Committee,* throw considerable light on the volatilization of silicon in the presence of sulphur, and on the conditions under which this occurs. Since receipt of Dr. Riley's communication we have taken the opportunity to examine the data contained in his paper with Mr. Preece, and we feel little doubt that the phenomenon he describes was due to the formation of SiS_2 (or other volatile sulphide of silicon) in the high-temperature zone of his apparatus. The simplest way of representing the equilibrium involved is in terms of the partial reaction :

$$SiO_2 + S_2 = SiS_2 + O_2 \quad \text{.....(1)}$$

where S_2, SiS_2, and O_2 represent the activities of these substances in the gas phase as given by their partial pressures. While the equilibrium constant of this reaction is unknown, it can be taken that in our own experiments the exceedingly low oxygen pressures existing in our hydrogen–H_2S atmospheres, together with the appreciable pressure of S_2 vapour resulting from dissociation of the H_2S, caused the reaction to proceed in the direction of SiS_2 formation, this being assisted by the volatility of the resulting SiS_2 which would be carried away in the gas stream.

The question that arises is, would this reaction be expected to proceed under the conditions described by Dr. Riley? These conditions are described as oxidizing, though this is, of course, a relative term. Actually from the thermodynamic data for the gas reactions involved, it can be shown that a mixture of 80 parts of nitrogen to 10 water vapour and 10 carbon monoxide would at 1200° C. and 1 atmos. pressure give a gas containing CO at a partial pressure of $2{\cdot}6 \times 10^{-2}$ atmos., CO_2 at $7{\cdot}3 \times 10^{-2}$ atmos., H_2 at $7{\cdot}3 \times 10^{-2}$ atmos., and H_2O at $2{\cdot}6 \times 10^{-2}$ atmos. (The data were calculated for 1200° C. but this is near enough to the temperature of Dr. Riley's experiments to indicate the order of the effects to be expected.) The equilibrium pressure of oxygen in the resulting gas phase would be approximately 10^{-11} atmos. This would be oxidizing to iron, the dissociation pressure of Fe-saturated FeO at this temperature being approximately 10^{-12} atmos. At the surface of contact with iron, therefore, the effective oxygen pressure would drop to this value. Decidedly lower effective pressures could, however, arise from contact with carbon in steels, the resulting oxygen pressure in the above gas mixture when brought to equilibrium with carbon at 1200° C. being approximately 3×10^{-19} atmos. with a hydrogen pressure of approximately 0·1 atmos.

With 0·2% of SO_2 in the gas mixture, the isolated gases at 1200° C. would contain SO_2 at $4{\cdot}5 \times 10^{-4}$, H_2S at $1{\cdot}6 \times 10^{-3}$, and S_2 vapour at $2{\cdot}5 \times 10^{-5}$ atmos. approximately. In contact with carbon the products would be primarily SO_2 at $1{\cdot}3 \times 10^{-17}$, H_2S at 2×10^{-3}, and S_2 vapour at 2×10^{-5} atmos. approximately. (Formation of SO has been neglected.) At the moment it is not clear whether SiS_2 would form under the first-mentioned conditions, though it seems fairly certain that it must do so under the second.

The position has been examined further as follows, though the approach is, of course, highly qualitative.

In reaction (1) above, the equilibrium pressure of SiS_2 under either of the given conditions is, of course, unknown, though it may be noticed that in the second case (carbon present) it will be approximately 10^7 times that in the first. Some idea of the actual order to be expected can possibly be got by considering the somewhat analogous reaction between magnesia and carbon which results in the formation of magnesium vapour and CO. At 1 atmos. of CO the equilibrium pressure of the magnesium vapour is of the order of 10^{-16} atmos., and the reaction can only be got to proceed at a reasonable rate at reduced pressure and when the CO formed is continuously drawn off. Silicon sulphide apparently forms more readily than this, so its equilibrium pressure under the conditions of Dr. Riley's experiments is probably of a higher order. Now, with 0·2% of SO_2 in the gas mixture, the maximum pressure of SiS_2 that could occur in the gas phase at the seat of reaction would be 0·001 atmos. Even if this represented equilibrium with the other reactants, the SiS_2 formed would be continually swept away so that reaction would still proceed. However, this gives us a figure to work on, and assuming that this pressure represented equilibrium when the gases were in contact with carbon, the equilibrium constant of reaction (1) would be approximately $1{\cdot}5 \times 10^{-17}$ at 1200° C.

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, February, pp. 213–234.

corresponding to a standard free-energy change of + 103,000 cal. for reaction (1). Taking $\Delta F.^\circ$ for the dissociation of SiO_2 at 1200° C. as + 145,000 cal., this would correspond to $\Delta F.^\circ$ = − 42,000 cal. for the reaction :

$$Si + S_2 = SiS_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This is considerably less than the value for the corresponding silica reaction, which is to be expected from the fact that platinum apparently readily decomposes SiS_2 at 1200° C. but has no effect on SiO_2. If the equilibrium pressure of SiS_2 were 1 atmos., the value of $\Delta F.^\circ$ of reaction (2) would be approximately − 75,000 cal. which may be rather high in view of its decomposition by platinum. Further, the fact that appreciable pick-up of silicon by the metal took place in our experiments would appear to be an indication that the equilibrium pressure in the present case would not be too high. On the other hand at much lower pressures it would seem unlikely that the reaction would proceed as rapidly as it does.

Similar calculations assuming an equilibrium pressure of 0·001 atmos. of SiS_2 in the gases in the *absence* of carbon gives $\Delta F.^\circ$ for reaction (2) of the order of − 90,000 cal. It is felt that this is probably too high for the reasons stated previously, and, at the moment, we feel that the presence of carbon in the steel or otherwise would be necessary for the formation of SiS_2 under the conditions outlined by Dr. Riley. This is consistent with the findings of Chaston, Edwards and Lever (*loc. cit.*) who found that, for the contamination of platinum thermocouples, carbon as well as sulphur had to be present. Under our own conditions this would probably not be necessary owing to the very low oxygen pressures obtaining.

A point of some practical importance arising from the foregoing is that under the conditions of Mr. Preece and Dr. Riley's experiments the SiS_2 would presumably be largely formed from silicon in the steel. If so the silicon steels would logically be expected to show a decrease in scaling resistance in atmospheres containing SO_2 to a greater extent than would steels low in silicon. Examination of their results shows that this is indeed the case. Thus Fig. 4 of their paper shows that the 4% silicon steel, which had the best scaling resistance in sulphur-free atmospheres, scaled most rapidly in the presence of SO_2, while the 3% silicon, 9% chromium steel showed the next most marked effect. Even amongst the " non-silicon " steels a trend with silicon content is suggested by the fact that the 12% chromium steel which contained 0·54% of carbon was the next most badly affected while at the other extreme the 3½% nickel, ¾% chromium steel which had the lowest carbon (0·14%) was the least affected.

It is further suggestive that, as shown in their Fig. 8, the progressive addition of oxygen to the SO_2-containing gases caused the scaling rate of the 4% silicon steel to pass through a maximum at 2% oxygen addition, after which it fell markedly with higher oxygen additions—this in spite of the fact that the atmosphere was becoming more oxidizing. While this might be contributed to by the inhibiting effect of oxygen on the formation of ferrous sulphide in the scale, it could also be expected from its inhibiting effect on the formation of SiS_2.

Regarding our own results, it is not altogether clear yet why the presence of silicon in the metal should have (as appeared to be the case) tended to raise the value of the equilibrium constant. Expressing the equilibrium involved in the form :

$$2Fe + SiS_2 = Si + 2FeS,$$

where SiS_2 is measured in the gas phase and the others as concentrations in the metal, it will be seen that at constant pressure of SiS_2 raising the silicon would cause a lowering in the equilibrium concentration of FeS. At equilibrium, however, the concentration of FeS in the metal would be determined by the H_2S/H_2 ratio in the gases, so the main effect of the above reaction would be to limit the concentration of the silicon, unless, of course, a steady state rather than an equilibrium state was being measured. At the moment a more likely explanation might be that the formation of SiS_2 caused an effective lowering of the " free " sulphur content of the gases in the hot zone. The fact that, on the whole, good agreement was got between ingoing- and outgoing-gas compositions does not invalidate this suggestion, as the rapid deposition of silica in the outlet tube shows that this reaction was largely reversed as the gases were leaving the furnace. Another possibility is that the presence of appreciable amounts of silicon in the iron would affect its activity.

Before concluding we should like to comment on the diverse implications of the silicon–sulphide reaction. We already have evidence of its effects on such diverse phenomena as the reaction of H_2–H_2S atmospheres with liquid iron, and the embrittlement of platinum thermocouples. We have also suggested that it may have a bearing on certain aspects of the scaling of steels. It now seems likely that it may play a part in several other phenomena which have hitherto been rather obscure. Thus it has been known for some time that under certain conditions atmospheres containing SO_2 tend to " rot " silica bricks, while in firing ceramically bonded silicon carbide abrasive wheels it is recognized that the combination of high sulphur in the fuel and a reducing atmosphere may have a deleterious effect on the quality of the fired product. Lastly, the presence of silica in fume drawn from an electric-arc furnace, and the evolution of H_2S from the fume on acid treatment, have been reported in a previous paper to the Institute.* It is quite likely that silicon sulphide formation is at least partly responsible for the presence of silica in such fumes, as conditions during the reducing period would be eminently suitable for its formation.

Yours faithfully,

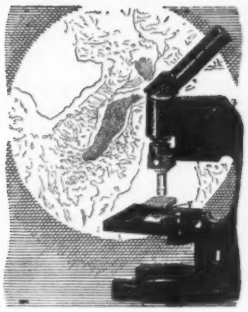
JAMES WHITE,
H. SKELLY.

Refractories Department,
University of Sheffield.

* *Journal of the Iron and Steel Institute*, 1945, No II., p. 341 P.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Mechanism of Corrosion Fatigue of Steel in Acid Solution*

By M. Tchorabdji Simnad† and U. R. Evans†

SYNOPSIS

Corrosion fatigue in hydrochloric acid shows certain analogies to, but also marked differences from, that in potassium chloride. At the end of an incubation period, rounded pits develop into cracks, the residual strength sharply declines, the rate of chemical corrosion (hitherto constant) greatly increases, and the potential drops ; these four changes occur sooner at high than at low stress ranges. A cathodic current can prevent detectable chemical attack but does not greatly increase life. The results are best explained by the changes produced by stress within the metal, in contrast to a rupture of films, which may often be important in neutral solutions.

INTRODUCTORY SECTION

Early Researches on Corrosion Fatigue

THE discovery of corrosion fatigue was made by Haigh about 1917 during a study of the service breakage of paravane wires, which were found to fail far below their tensile strength if subjected simultaneously to vibration and the chemical action of sea-water. He also studied[1] the damage produced on brass by ammonia vapour in the presence of alternating stresses, and demonstrated that corrosion and mechanical forces acting simultaneously produced more weakening that when they operated one at a time ; this was, however, a somewhat special case of conjoint action, since, as emphasized by Haigh, the decomposition of the β constituent of the brass appeared to play an important part in the results obtained. In succeeding years, many of the premature failures met with in engineering practice were ascribed to conjoint action. They appeared to be most frequent where there had been a tendency to reduce the factor of safety.

Between 1926 and 1931 McAdam[2] studied the behaviour of a number of materials exposed to alternating stress in the presence of corrosive waters under a variety of carefully controlled conditions of stressing. Special interest attaches to his two-stage procedure ; in the first stage specimens were subjected to corrosion fatigue for a period insufficient to produce fracture, and in the second stage the fatigue limit in air was determined, so as to obtain a measure of the damage produced in the first stage. The experimental data were presented in a number of different types of diagrams. McAdam's extensive work still provides the main experimental basis of our present knowledge. His theoretical view, gradually developed during his researches but only expounded fully in 1940, was that cyclic stress modified the forms of the pits, " mainly by increasing the permeability of the anodic coating."

* Paper No. 22/1947 of the Corrosion Committee, received 24th January, 1947. This paper is published by authority of the Corrosion Committee. The views expressed are the authors' and are not necessarily endorsed by the Committee as a body. The Corrosion Committee was transferred to the direction of the British Iron and Steel Research Association as from 31st December, 1946.

† Cambridge University.

In a comprehensive lecture delivered in 1932, Gough[3] rendered a great service by gathering together into an easily assimilable form the somewhat scattered data provided by the work of McAdam and others. In surveying the results, he attributed the increased damage to the effect of cyclic strains on the continuity of the films which, under stressless conditions, would tend to stifle corrosion. Bengough[4], discussing one of Gough's papers, suggested that the action of cyclic stresses was connected with an enhanced supply of oxygen at the point of attack.

In the same year Gough and Sopwith[5] published an experimental study of the behaviour of a single crystal of aluminium immersed in a stream of tap-water and under alternating torsional stress. The tests were interrupted at various stages, and the specimens subjected to microscopic and X-ray examination. They observed :

(1) General pitting attack (a large number of very small corrosion pits).

(2) Local attack with larger pits.

(3) Slip bands with preferential corrosion on the site of previously formed slip bands, cracks, and general break-up of the surface.

In a later research a specimen containing two crystals was used, and they found that the boundary did not influence the method of failure, which again took place by the formation of cracks in areas undergoing heavy plastic deformation. Gough[6] also reported that for some materials (copper and brass) the normal fatigue life of metal was lengthened if the experiments were carried out in a vacuum. This was attributed at the time to the exclusion of oxygen, but Gough's later experiments rather suggested that the exclusion of water vapour was more important.

About that time Bacon[7] made a fruitful study of the formation of cracks in rods subjected to fatigue and corrosion fatigue. His results show that corrosion-fatigue cracks start at pits and then extend all round the periphery. As the breakage is the result of many cracks starting from different corrosion pits and in different transverse planes, the fracture is irregular in character.

Meanwhile much work which had been done on the prevention of corrosion fatigue by coatings brought out clearly the fact that a coating which was anodic towards the basis metal was much more beneficial than a coating which was electrically neutral, whilst coatings which were cathodic might even have an adverse effect. This was in accord with an early observation of Behrens[8] that cathodic treatment, produced by an external E.M.F., also retarded corrosion-fatigue damage. The excellent effect of zinc coats, even when interrupted, had been brought out in the early work of Haigh[9] on paravane wires. Later Gerrard and Sutton[10], studying the corrosion fatigue of duralumin, found that zinc plating produced a substantial improvement, whilst cadmium plating was of little use. Similarly, Krystof[11] showed that, on steel, tin coatings gave far less protection than zinc plating.

Previous Work at Cambridge

In 1934 Gould[12] studied the corrosion of iron wire in the presence and absence of alternating stresses. The damage was estimated in four ways, namely, by loss of (1) weight, (2) electrical conductivity, (3) tensile strength, and (4) fatigue strength. When loss of weight or electrical conductivity was adopted as a criterion of damage, alternating stressing did not raise the rate of damage above that produced by corrosion in the absence of alternating stress. The work based on tensile strength was indecisive, but, when fatigue strength was adopted as criterion, it was found that superimposition of alternating stresses during corrosion greatly increased the rate of damage. This showed that failure is connected with some form of cavity which produces no appreciable increase of weight loss or conductivity loss, but a considerable loss of fatigue strength. The only type of cavity which fulfils these conditions is a sharp-ended crack. (The contrast between the sharp fissures produced during corrosion fatigue and the hemispherical cracks produced by stressless corrosion was afterwards clearly brought out in the photographs of McAdam and Clyne.[13])

In 1939 Gould and Evans[14] studied the electrochemical conditions of wires subjected to corrosion fatigue in chloride solutions to which chromate had been added as an inhibitor. (The inhibitive action of chromates under corrosion-fatigue conditions had been demonstrated by Speller, McCorkle, and Mumma[15] as early as 1929.) It was found that the electrode potential suddenly underwent a change when a breakdown of the protective film formed by the chromate occurred, and it was thus possible to measure the film-life as well as the wire-life (the period needed for breakage of the wire specimen). Both film-life and wire-life were found to diminish with increase of the stress or of chloride concentration, but were lengthened by an increase in the chromate concentration.

The same work confirmed the fact that contact with zinc prolongs life under corrosion-fatigue conditions. It was feared, however, that in acid environments the zinc might conceivably embrittle the steel by charging it with hydrogen. This possibility was examined by Stuart and Evans,[16] who found that the danger was negligible, and that under most conditions contact with zinc

greatly increases resistance to corrosion fatigue. Huddle and Evans[17] in 1944 obtained an increase of life in the presence of sea-water by the application of a paint richly pigmented with zinc powder; as shown by Mayne and Evans,[18] with a proper choice of vehicle, paints may be obtained which yield a coating containing 95% of metallic zinc. In such cases protection is obtained even if the covering is incomplete.

The present authors[19] in 1943–1945 studied the corrosion fatigue of steel wire wetted by potassium chloride solution, with a view to establishing the electrochemical mechanism of the corrosion-fatigue process. Most of the experiments were interrupted before fracture had occurred, in order to ascertain the progress of the weakening. Others were continued to fracture, and in several cases the electrode potential was measured during the progress of corrosion fatigue.

In another series of experiments, a cathodic current was applied throughout the tests, so as to ascertain its effect in (1) reducing the rate of chemical attack, (2) diminishing the number of cracks, and (3) lengthening the life. The results suggested that alternating stresses increased the rate of damage, partly by improving the supply of oxygen, which would stimulate the *cathodic* reaction, but that the *anodic* reaction was also facilitated either by the rupture of protective films or by the distortion of the metal, which would tend to make it more reactive.

Object of the Present Work

In neutral salt solutions, it is difficult to distinguish between the effect of film rupture and that of the distortion of the underlying metal. It appeared likely, therefore, that experiments carried out in acid solution, where oxide films would not easily be formed (or if formed, would rapidly be destroyed) might throw light on the mechanism of corrosion fatigue. Accordingly the series of experiments described in the present paper were carried out.

Experimental Method

The materials and apparatus used were the same as in the previous research, and only a brief description is needed.

Materials

The specimens used were cold-drawn mild-steel wire, 15 in. long and 0·1 in. in diameter. The ultimate tensile strength was found to be 48 tons/sq. in. and the air fatigue limit ± 21 tons/sq. in. The chemical analysis of the steel was as follows:

C,%	Si,%	S,%	Mn,%	P,%
0·19	0·07	0·03	0·78	0·02

Apparatus

A Haigh-Robertson fatigue-testing machine has been used for subjecting the specimens to alternating stresses. The bowed wire is rotated at 6000 r.p.m., and the corrosive solution is allowed to flow over the central length of 5 mm., where the bending stress is maximal. The arrangement for applying the corrosive solution consists of a vertical glass rod waxed over its entire surface, except for a channel along the side nearest the specimen (Fig. 1). The liquid flows down this channel and forms a continuous ring around the wire at the required point; it then

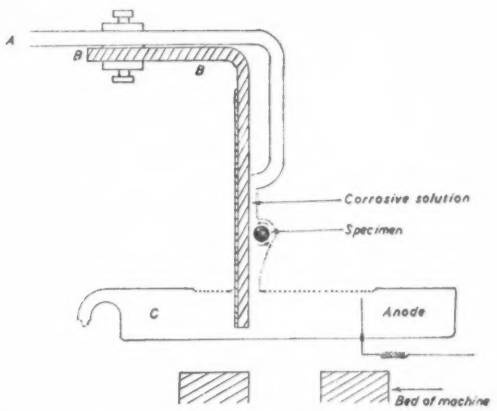


Fig. 1—The arrangement for applying the corrosive solution

descends into a special horizontal tube, *C*, from which it pours out into a beaker. A platinum-foil anode is fused into the tube *C*, and when a current is to be applied to the specimen, a high external resistance is used in conjunction with a high external voltage in order to minimize small changes in the resistance of the liquid portion of the circuit.

The corrosive solution used was *N*/10 hydrochloric acid. The iron passing into solution was estimated colorimetrically by the use of a Spekker photo-electric absorptiometer; thioglycollic acid was used as the reagent.

Measurement of Electrode Potentials

The specimens were connected to a saturated-calomel electrode by means of a wet filter-paper strip, supported by the waxed rod down which the acid flowed, through a bridge of deci-normal potassium chloride. Electrical connections led to a Cambridge valve potentiometer. The potentials could be measured within a minute after the liquid had made contact with the specimen, with an accuracy of ± 0·5 mV.

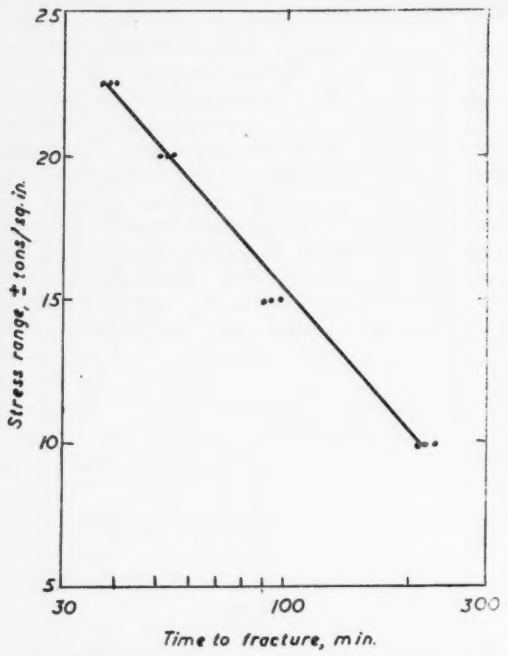


FIG. 2—Life to fracture in $N/10$ hydrochloric acid

EXPERIMENTAL RESULTS

Series I—One-Stage Experiments

The acid solution was applied up to fracture at various ranges of stress. The results, plotted in Fig. 2, show the usual linear relationship between the stress range, S, and the logarithm of the number of cycles to fracture, N, namely $N=Ce^{-kS}$, where C and k are constants.

Series II—Two-Stage Experiments

The flow of the corrosive solution was stopped after a definite period and the specimen was dried and subjected to the same range of alternating stresses in air. Thus the damage inflicted on the specimens by various periods of corrosion fatigue was assessed by taking the remaining life as the criterion of damage. In Fig. 3 the total lives (*i.e.*, the sum of the two periods) are plotted against the corresponding periods of corrosion fatigue. The curves obtained indicate that at each stress range a definite period of corrosion fatigue can be tolerated by the specimens with safety. If the corrosive is applied for a period longer than this "incubation stage" the total life is greatly reduced. In fact the resultant total life is then scarcely longer than that obtained with the acid applied right up to fracture.

A feature which attracts attention in Fig. 3 is the increase in total life, at high ranges of stress, when the corrosion-fatigue stage exceeds a critical value; there appears to be a minimum total life corresponding to a definite corrosion-fatigue period.

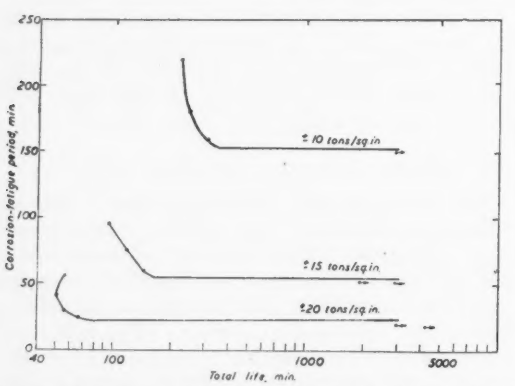


FIG. 3—Influence of corrosion-fatigue period on total life

Series III—Influence of Stress Range on Corrosion Velocity

The effect of alternating stresses on the rate of solution of iron in acid is clearly shown in Fig. 4. Here the passage of the iron into the combined

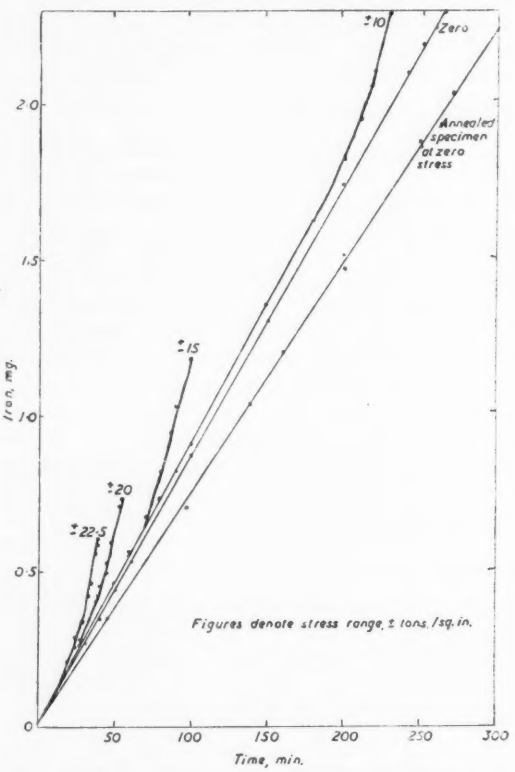


FIG. 4—Rates of corrosion in $N/10$ hydrochloric acid

state is not likely to be disturbed by the presence of any oxide films, or by a blanket of corrosion products, since these are readily soluble in the acid. It will be seen that initially the stress range hardly affects the corrosion velocity, which at zero stress remains constant throughout the experiment. In the experiments under stress, there occurs shortly before fracture a marked increase in the rate of solution of the iron. When the stress range exceeds the air fatigue limit, the rate of corrosion increases from the outset; conversely, for annealed specimens (where both external and internal stresses are excluded) the constant rate of corrosion is less than that of the cold-drawn specimens.

In Fig. 5 the logarithm of the times at which the rate of corrosion suddenly increases is plotted against the corrosponding ranges of stress. The straight line obtained indicates a simple exponential relation between this time and the stress range.

There is a close correspondence between the safe periods found in the two-stage experiments

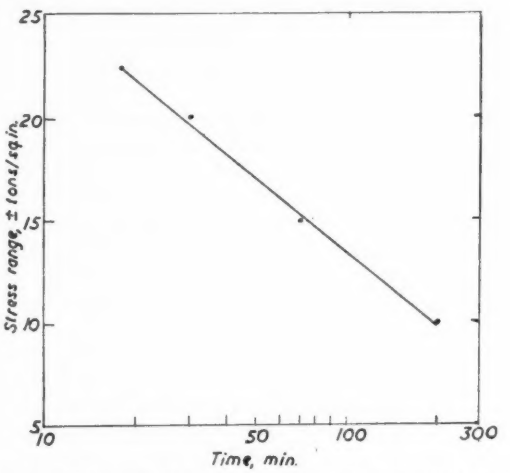


FIG. 5—Influence of stress range on time at which the corrosion rate increases

and the time over which the rate of corrosion is constant. When this period is exceeded, the mechanical damage greatly enhances the corrosion-velocity.

Series IV—Influence of Applied Cathodic Currents

There was a great scatter in the values obtained with applied currents. The results recorded in Table I show that a cathodic current only slightly prolongs life; this stands in strong contrast with the results obtained in neutral salt solutions, where a sufficient cathodic current density produced a very great increase in life. On the other hand, the rate of passage of iron into the combined

TABLE I—*Influence of Applied Currents on Life to Fracture*

Stress Range, ± tons/sq. in.	Applied Current, m. amp.	Life to Fracture, min.
20	zero	51, 53, 55
20	0·100	53, 48, 50
20	0·250	65, 56, 53
20	0·500	66, 71, 74
20	1·000	71, 119, 122, 95
20	2·000	119, 95, 120
10	zero	219, 230, 215
10	0·100	255, 241, 247
10	0·250	261, 253, 237
10	0·500	357, 351, 320
10	1·000	353, 366, 317
10	2·000	311, 362, 340

state, as shown in Fig. 6, was very greatly diminished by the application of a cathodic current. Indeed, when the current applied was sufficiently large, no iron could be detected in the liquid, although the life of the iron was barely doubled; the current strength needed to prevent iron passing into the liquid increased with the stress range.

Series V—Measurements of Electrode Potentials

The time/potential curves drawn in Fig. 7 show that there is little difference initially between the curves obtained at various ranges of stress, but shortly before fracture a sudden fall in potential takes place. This fall in potential is clearly related to the results obtained both in the two-stage experiments and in the estimation of corrosion velocities. The three phenomena, namely, (1) the end of the safe period in the two-stage experiments, (2) the increase in the

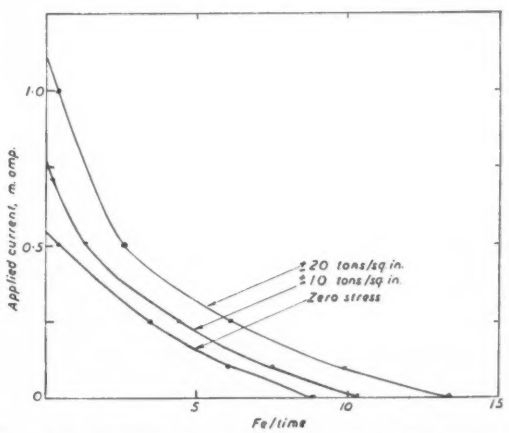


FIG. 6—Average rates of corrosion with applied current

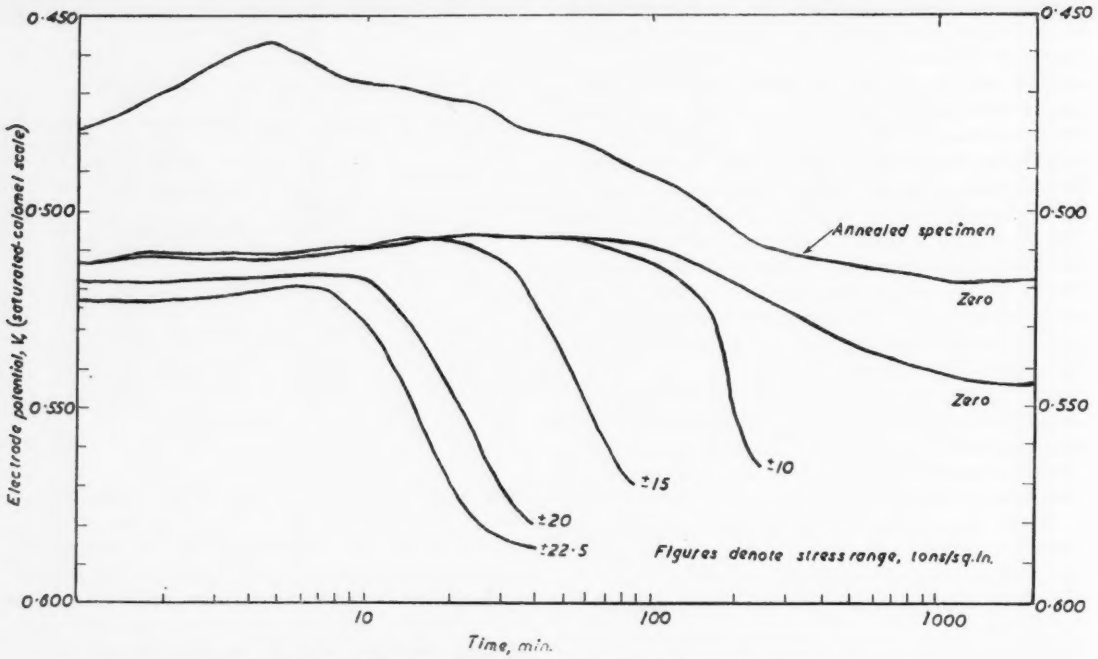


FIG. 7—Influence of stress range on time/potential curves

rate of corrosion, and (3) the fall of potential, are practically coincident.

The point of greatest interest in these time/potential curves is the fact that the final potentials reached differ appreciably from each other. The fracture of the specimens limited the time over which the potentials could be measured. Nevertheless, the final potentials reached at all ranges of stress were well below the steady potential obtained at zero stress in long-continued experiments. This is in marked contrast to the situation in salt solutions, where, although the *rate* of fall of potential increased with the stress range, the same *final* value was reached in all cases. It is also of great interest to note that the time/potential curve for the annealed specimen lies throughout at a higher (more noble) potential than those for the cold-drawn specimens. The final steady potential of the annealed specimen differs from that of the cold-drawn ones by over 40 mV.

The time/potential curves obtained with cathodic currents superimposed are shown in Figs. 8, 9, and 10. The results obtained with larger currents were not reproducible, and the curves drawn are those for the lower currents only. Here again there is little difference between the initial values of the potentials, but shortly before fracture the potential falls rapidly. The values of the potentials at fracture are not much altered when a small cathodic current is applied.

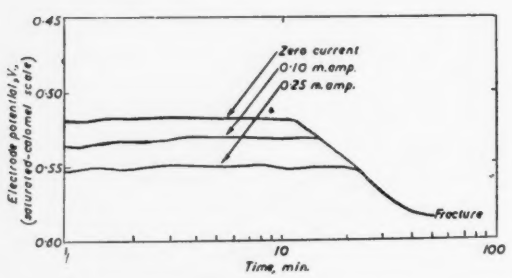


FIG. 8—Influence of applied currents on electrode potential at ± 20 tons/sq. in.

DISCUSSION

The Effect of Corrosion Period on Total Life

The shape of the curves shown in Fig. 3, in conjunction with microscopical examination, suggests that corrosion fatigue takes place in three stages. In the early stages the corroded area consists of small hemispherical pits, none of which gives rise to a sufficiently high concentration of stress for the initiation of a crack. If the corrosive is removed at this stage and the experiment continued in air, the specimen has a long life. If the corrosion period is continued beyond this stage, then one of the pits which happens to be deeper and sharper than its neighbours will extend into a crack. The explanation suggested to account for the transformation of a hemispherical into a V-shaped pit is as follows : The stress

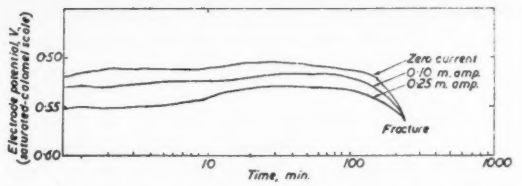


FIG. 9—Influence of applied currents on electrode potential at ± 10 tons/sq. in.

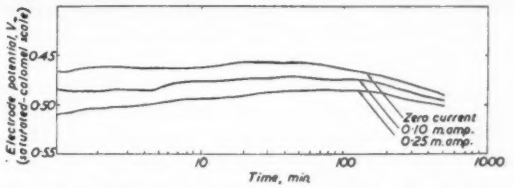


FIG. 10—Influence of applied currents on electrode potential at zero stress

concentration present at the bottom of the pit and along the periphery makes these the most anodic parts in relation to the cathodic surface. The pits will thus extend downwards and along the periphery, becoming increasingly sharp in the process. The corrosion becomes intense because it is concentrated on the narrow anodic area, and digs rapidly into the metal.

The third stage is reached when, with longer periods of corrosion, the total life begins to increase again. The following explanation is offered for the appearance of this stage: The extension of the deepest pit downwards during the corrosion stage does not proceed independently or at a constant rate. When once it has extended into a crack the E.M.F. between its apex and the metal surface will assume a limiting value. At the same time the increasing resistance of the cell with depth will cause the corrosion current to decrease, the result being a slowing down of the progress of this pit. During this period other pits will also be developing into cracks, so that in time a large number of neighbouring cracks are produced. Now it is well known that the concentration of stress at a discontinuity is appreciably modified by the presence of adjacent discontinuities. It is to be expected, therefore, that the mutual interference of the stress concentrations around a group of adjacent fissures will dilute the intensity of a stress caused by the few cracks produced in the second stage. If at this advanced stage of corrosion the specimen is dried and the test continued in air, the total life may be longer than if the corrosion had been suspended at the intermediate stage.

In potassium chloride solution this phenomenon is very marked, but in acid the turning over of the curves only occurs at the highest stress range, and even there it is less pronounced. The difference possibly lies in the more general nature of the corrosion produced in acid solution; the attack may become still more general at low stress ranges, owing to the longer time available.

Influence of Stress Range on Corrosion Velocity

The effect of alternating stresses and of cold work on the rates of corrosion in acid differs markedly from the corresponding effect in salt solutions. In the latter, the corrosion velocity increased with stress range from the start, but was constant with time. This in itself did not allow any definite conclusions to be drawn, since it was amenable to several explanations. Owing to the presence of oxide films and of corrosion products, it could be attributed to (1) an alteration in the potential of the local anodes, (2) a decrease in anodic polarization, or (3) a decrease in cathodic polarization. On the other hand, such ambiguity does not exist when an acid corrosive is used, since the oxide films and the corrosion products are readily destroyed by acid (the former by reductive dissolution, not direct attack[20]). Thus curves obtained in acid serve to clarify the position regarding the influence of stress range on the corrosion velocity of the bare metal. At zero stress the corrosion velocity is constant with time. With applied ranges of stress the initial rates of corrosion hardly differ from the rate at zero stress, showing that within the elastic range alternating stresses have little influence on corrosion velocity. But the rapid increase in the rate of solution of iron shortly before fracture reflects the fact that mechanical damage greatly enhances corrosion velocity. That is, as soon as fissures are formed which extend into cracks and produce appreciable distortion or disruption of the crystalline structure, the metal becomes more reactive. Similarly, the fact that an annealed specimen dissolves at a slower rate than a cold-drawn specimen seems to confirm the view that distortion of the lattice facilitates the rate of passage of iron into solution, although here the enhanced corrosion might be due to an alteration of phase distribution on annealing. Further evidence is provided by the fact that at a range of stress above the air fatigue limit, where the material is being plastically deformed from the commencement of the test, the rate of solution increases almost from the start.

Effect of Applying Cathodic Currents

It is well known that the application of a cathodic current diminishes the rate of corrosion of iron, while stirring of the solution increases the current required for conferring a given amount of protection. High current densities were required,

therefore, for preventing corrosion of the rapidly rotating specimens used in these experiments.

The decrease in the average rates of passage of iron into the combined state was in harmony with the results obtained in salt solutions, except that the current density required for a given amount of protection was greater for the acid solution, as would be expected.[21]

The current needed to prevent iron passing into the liquid in detectable quantity also increased with the stress range. According to the theoretical

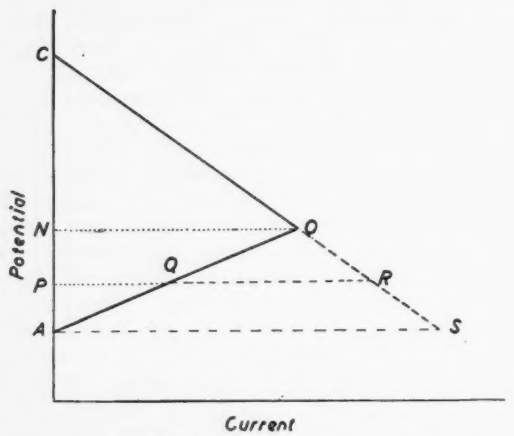


FIG. 11—Effect of applied cathodic current on corrosion rate

treatment developed independently by Hoar[22] and by Mears and Brown,[23] the application from an external source of a cathodic current equal to QR (*see* Fig. 11) should reduce the corrosion rate from the equivalent of current PR to the equivalent of PQ ; if the potential is reduced to A (the potential of the metal in the absence of an anodic current) corrosion should be prevented altogether. The fact that the current needed for protection becomes higher with increasing stress range is easily explained on the assumption that stressing beyond the elastic range depresses the electrode potential of the metal.

The results as a whole are easily explained if the potential relations are altered by stress in the manner indicated in Fig. 12, which suggests how stress increases the corrosion rate (from the equivalent of NP to that of $N'P'$), depresses the potential (from P to P'), and increases the current needed for protection (from the equivalent of AS to that of $A'S'$).

The general conclusion is that the action of alternating stress in corrosion fatigue in acid is attributable to distortion of the metal rather than to rupture of obstructive films.

The fact that a current which effectually prevents the appearance of iron in solution nevertheless does not greatly prolong life is probably attributable to the fact that the applied current hardly reaches the tip of a crack, so that the attack at this part, and consequently the rate of damage, remains almost unchanged. The iron salts produced are, however, redeposited by the cathodic current at or near the mouth of the cracks, thus explaining the absence of iron in the liquid flowing away.

An Alternative Interpretation of the Results

A different explanation has been kindly suggested by Dr. Mayne, based on the assumption that the number of cracks suddenly increases just before fracture. He explains the difference between the potential-movements in acid and neutral solution respectively by the fact that control is partly anodic in acid liquids, but almost purely cathodic in neutral liquids ; the increase in area accompanying the formation of cracks will, therefore, diminish anodic polarization and depress the potential in acid solution, but produce little effect in neutral solution. He likewise attributes the increase in the rate of passage of iron into solution to the diminished anodic polarization. The increase in the current required for protection at high stress is regarded as due to the fact that, when the area to be protected is increased by cracking, a given current represents a smaller current density. The authors, however, feel that the basic assumption (that corrosion fatigue converts pits into cracks) itself requires an explanation ; for if the supply of corrosive liquid is discontinued before cracking starts, the life is very long. The simplest explanation is that plastic stressing renders the metal more active and therefore more anodic.

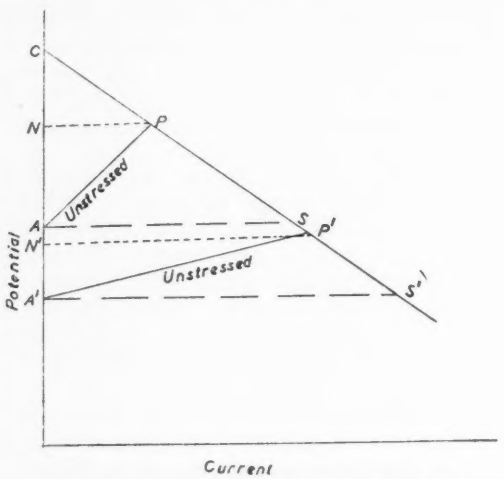


FIG. 12—Effect of stress on corrosion rate

Summary

The corrosion fatigue of steel wire in acid has been followed by : (1) Measuring the residual air fatigue strength in experiments interrupted at different stages ; (2) studying the changes microscopically ; (3) determining the iron passing into the combined state ; and (4) measuring the changes of electrode potential. Changes in (1) and (2) show a close analogy to those previously obtained with neutral potassium chloride solution, but marked differences are observed in respect of (3) and (4).

During the opening stages, rounded pits are formed and there is no serious loss of fatigue strength ; after a certain incubation period, cracks develop, the fatigue strength drops catastrophically, the rate of chemical corrosion (hitherto constant) greatly increases, whilst the potential is shifted in the base-metal direction. This remarkable change occurs sooner at high stress ranges than at low ones. The results support the view that, although elastic deformation does not affect the chemical or electrochemical properties of the iron, deformation beyond the elastic limit (which may occur if pits produce stress intensification) alters these properties, making the iron behave like a more reactive metal.

The application of a cathodic current greatly reduces the passage of iron into the combined state ; if the current is sufficiently high, corrosion may cease entirely (the current density required for this increases with increase of stress range) ; the life of the specimen is not greatly prolonged—in contrast to the results previously obtained in neutral salt solutions.

Acknowledgments

The authors wish to acknowledge the generous support of the British Iron and Steel Research Association, and the encouragement given by the Iron and Steel Institute Corrosion Committee—particularly by the Chairman, Professor Wesley Austin. They would also thank Dr. A. J. Gould. Dr. J. E. O. Mayne, Dr. J. N. Agar, and Mr. D. Whitwham for much fruitful discussion.

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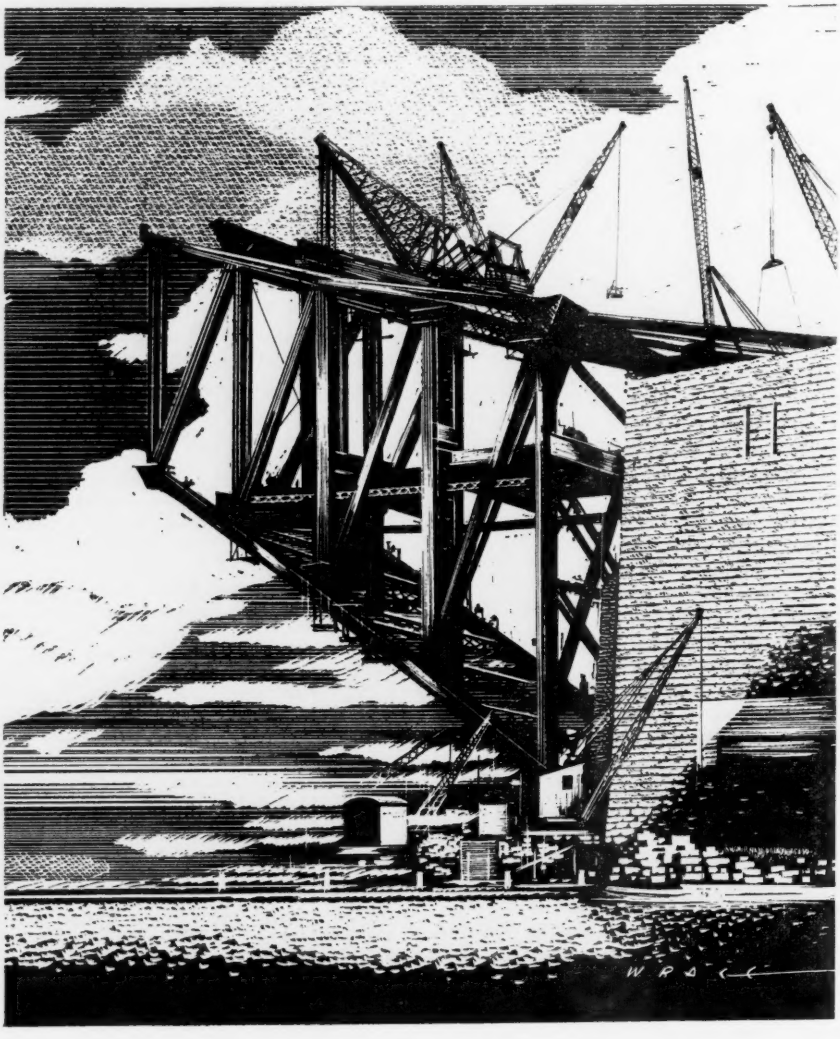

IRON AND STEELWORKS ENGINEERING

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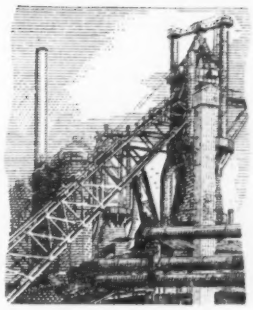


THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE FOURTH MEETING

THE FOURTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 11th June, 1947. In the absence of Mr. W. F. CARTWRIGHT, Chairman of the Group, the Chair was taken by Dr. C. H. DESCH, F.R.S., President of the Institute.

THE MORNING SESSION was devoted to a discussion on "Steam Generation and Utilization in Iron and Steel Works," based on the following two papers, which were printed in the May, 1947, issue of the *Journal*: "Water-Tube Boilers for Iron and Steel Works," submitted by the Water-Tube Boilermakers' Association, and "Steam Turbines for Iron and Steel Works," by I. V. Robinson.

THE AFTERNOON SESSION was devoted to the presentation and discussion of a paper on "Gas Turbine Applications in Iron and Steel Works," by A. T. Bowden, W. H. Gibson, J.W. Railly, and R. G. Voysey. The Proceedings of the Afternoon Session will be published in the September issue of the *Journal*.

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

Discussion on STEAM GENERATION AND UTILIZATION

Mr. **A. S. Peacock** (Messrs. Babcock and Wilcox, Ltd.), who presented the first paper, said: I should like first to thank you on behalf of the Water-Tube Boilermakers' Association for the opportunity to present a paper of this nature. When the three authors first discussed this question, we found ourselves in a quandary; the title embraced such a wide field that we could have written twenty papers rather than one, and we had to decide whether to make a detailed study of one facet of the problem or to try, in about seven thousand words, to telescope the whole of the problem into one paper. In the end the latter course was adopted, and we must request your indulgence if some of the items have been scamped. It was felt, however, that if the subject was presented in this overall manner we could be a little controversial, and we could hear of the problems that are worrying you.

There are one or two fundamentals, and the first is fuel. In the past, the steam-raising plant in the steel industry has been rather small and rather inefficient. From the point of view of commercial considerations—the economic point of view—the industry was probably justified in installing the plant which it now has, and in a few cases it is of outstanding merit. The fuel situation, however, has now completely changed, and the need for boiler plant of the highest possible efficiency commensurate with capital cost must, with the current costs of solid and gaseous fuels, be the guiding factor for the designer both on your side and on ours.

Water is another major problem. Steelworks are not put down specifically to take advantage of water conditions. It does not follow that you will always have condensing sets; the boiler does want feed-water, and there may be serious feed-water problems to counter. Again, whilst in a power station only a modest amount of make-up water is needed, in the average steelworks a very high percentage, which may have to be treated, is required.

With the overall problem of fuel and water you have to consider the capital cost of the boiler plant. If a high degree of thermal efficiency is

wanted it will cost a great deal of money, and if it will not pay for itself you will not buy it.

The trend today, as I see it, is that most steelworks are trying to close the thermal gap, as far as possible, with the comparatively waste fuels that are available, between the process-steam requirements and the electrical current that has to be generated ; but the very serious electrical loads that the rolling mills impose upon the generators encourage many to buy power from the grid and not attempt this particular balance between process-steam consumption and electrical output. Some plants have succeeded in avoiding the use of any solid fuel at all.

If you are getting near to the solution of the problem of balancing steam and electrical loads, and there is only a modest gap to close, there is a good deal of flexibility available with regard to pressure and temperature. You may require a large quantity of process steam at 100 or 150 lb./sq. in., but you need a certain amount of power, and, if you are somewhere near the balance, whether you put your initial boiler plant and generators in for 450 lb./sq. in. and 700° F. or for 600–650 lb./sq. in. and 800° F. may make all the difference between using a supply of solid fuel, or closing the thermal gap and having only some emergency standby liquid fuel.

That brings us to the question of auxiliaries. The higher pressures and temperatures give a higher electrical output per pound of steam, but also on the boiler side large economizers and large air heaters can be put in and the dry-gas losses leaving the stack reduced to a minimum, thus obtaining an extra 5, 6, or 8% of evaporation from the boiler plant with the same fuel consumption, provided that the economics of the job will warrant the expenditure. If it will close the thermal gap it is obviously worth while, because in many cases the result may be that elaborate coal- and ash-handling plant need not be installed.

As I see it, however, the moment it is found that a major contribution from solid fuel is needed in order to balance the load, solid-coal-firing equipment must be considered. This can be done with stokers on the one hand or pulverized fuel on the other. If the secondary fuel, as often happens, is coke breeze, I think there will be general agreement that the case is made out for stoker-fired plant. We can put forward a stoker-fired plant which will handle coal with both gases, or coal and coke breeze with both gases, or coke breeze alone with both gases. Coke breeze is not a satisfactory fuel for pulverized-fuel plant. If, therefore, coke breeze has to be utilized, let us regard the stoker-fired plant as the only sensible approach to the problem.

If, however, coal is the secondary fuel, the pulverized-fuel plant has much to recommend it, because the average load in a steelworks is very variable. Users have a habit of taking large quantities of steam from the boiler when it is least expected, and the pulverized-fuel-fired boiler is certainly more sensitive to these load changes and can follow them better than the stoker-fired plant.

With the pulverized-fuel-fired boiler there are various kinds of milling equipment and various kinds of firing, but the major problem is the constant steam temperature required by the man in the engine-room. Table I of the paper is given to try to bring to notice the wide difference in characteristics of the four fuels in question. It is easy to specify, when asking for boiler plant, that 600 lb./sq. in. pressure and 800° F. steam temperature are required, and that the economics of the plant necessitate contemplating three fuels. When one fuel happens to be blast-furnace gas, it can be seen that the volume for the same heat input is very substantially increased over the other fuels ; on the other hand, the furnace temperature is lower, and to some extent this is a compensation, but it is not enough. Therefore, since the heat transmission in the superheater is to some extent proportional to the mass gas flow over the surface, there is a fairly wide variation in the superheat when the various fuels are burnt in varying percentages, and the boilermaker has a number of ingenious methods of controlling the superheat. It can be done with external attemperators or internal gas dampers, and the engineer in the turbine room can be given a constant and reliable steam temperature ; but the point that I want to make is that it cannot be done without special plant.

This brings me to the question of automatic control. The broad interpretation of automatic control is that somebody puts in a switch and the whole plant looks after itself, and in an ordinary power station this is not far from the truth ; but in a steelworks, with varying fuels, it is extremely difficult. It is not impossible, but it is extremely difficult to put the whole plant on to automatic control. The boiler operator is very seldom in complete control of the amount of either fuel that is available, and so, generally speaking, it resolves itself by fixing in advance the air/gas ratio between coke-oven gas and forced draught and between blast-furnace gas and forced draught, and allowing the air and the gas to vary in proportion. When the other users take either of those gases for the internal circuit of the steelworks, and reduce or increase the surplus balance to the boiler-house, a fully automatic control would be concerned also with controlling the amount of solid fuel and the amount of air that has to be supplied with the solid fuel in

order to keep the boiler pressure steady, and the automatic control could not increase the amount of blast-furnace gas or coke-oven gas being supplied to the boilers.

This normally leads to a problem on the forced-draught side. One forced-draught fan can usually give all the air that is required for combustion with any of the fuels, but if a ratio is to be established in advance for coke-oven and blast-furnace gas, and if a secondary impulse from the main automatic control is to determine how much air is going to the solid-fuel fire, then when the blast-furnace-gas quantity varies, the air also varies automatically, and there will be a change of pressure in the branch duct supplying the solid fuel. It would then vary the coal supply and automatically with this change the air pressures, and flows to both gas and coal would change more than had been contemplated. A correction would take place and the air/gas ratio controllers would be hunting against the solid-fuel/air ratio controllers. It is the considered view of the boiler-makers, therefore, that for these conditions two forced-draught fans should be installed ; this will give to some extent a reliable automatic control for a dual- or a triple-fuel-fired boiler.

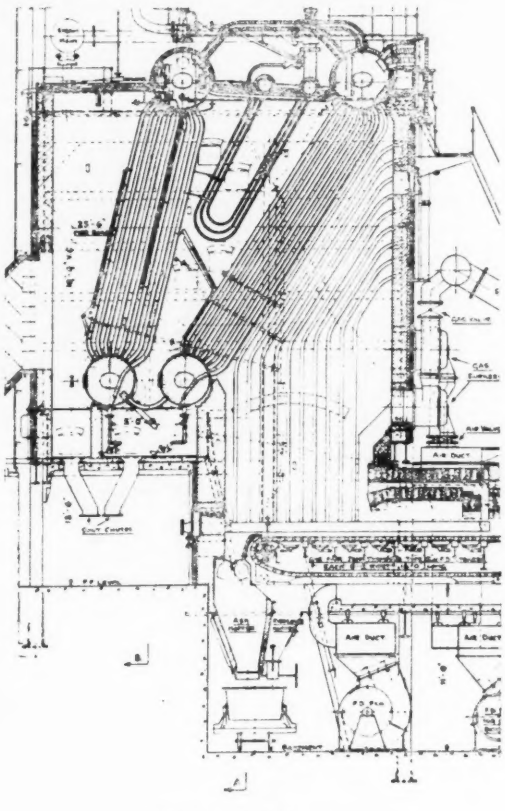


FIG. A—Stoker-fired boiler suitable for an evaporation of 42,000 lb./hr. at 160 lb./sq. in. Fired by coal and/or coke and blast-furnace gas

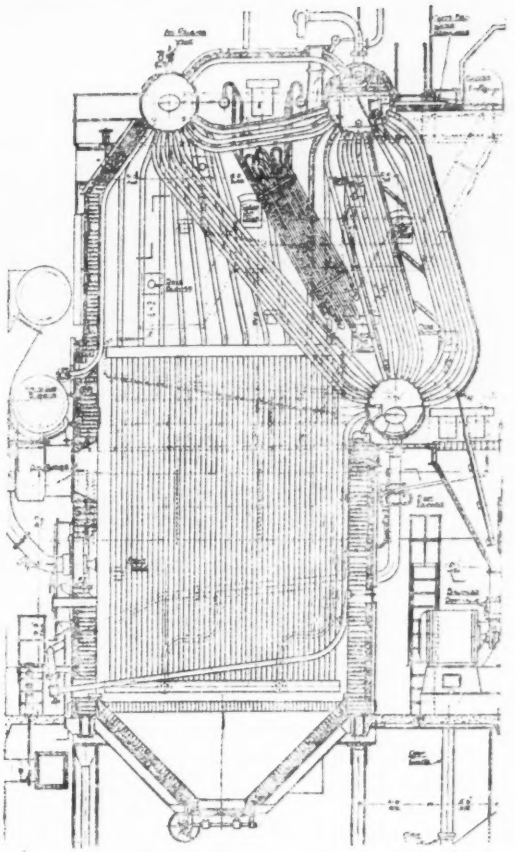


FIG. B—Boiler designed for normal load of 50,000 lb./hr. with a short-term peak of 65,000 lb./hr. at 375 lb./sq. in. and 725° F. Fired by blast-furnace gas and/or pulverized fuel

I should like to discuss a few typical examples of boiler plant. Figure A shows a stoker-fired boiler suitable for an evaporation of 42,000 lb./hr. at 160 lb./sq. in., for coal and/or coke and blast-furnace gas. Provision is also made for burning 100% blast-furnace gas. This plant is installed in South Wales.

Figure B shows a boiler designed for a normal load of 50,000 lb./hr., with a short-term peak of 65,000 lb./hr. The pressure is 375 lb./sq. in., 725° F. S.O.T., fired by blast-furnace gas and/or pulverized fuel. All the burners are mounted in the front wall, and the other three walls are water-cooled. This is a three-drum boiler with a pendant-type superheater, with a plate-type air heater incorporating by-passes on both air and gas sides, the air heater being arranged for re-circulation. With the changing gas volumes and

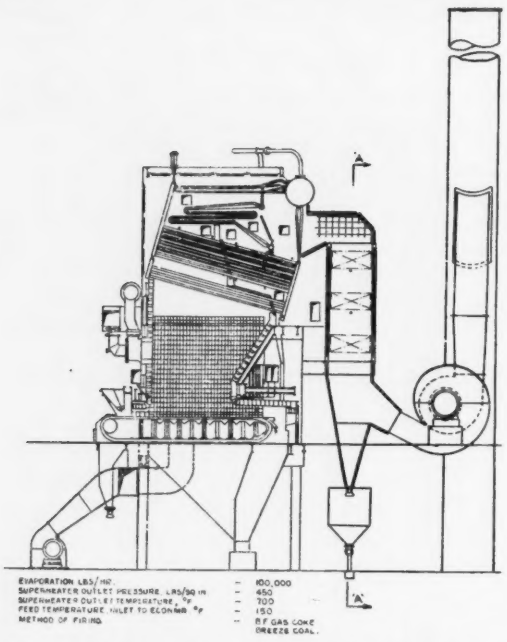

EVAPORATION LBS/HR. = 100,000
SUPERHEATER OUTLET PRESSURE LBS/SQ IN = 450
SUPERHEATED OUTLET TEMPERATURE °F = 700
FEED TEMPERATURE INLET TO ECONMR °F = 150
METHOD OF FIRING = P.F. GAS COKE BREEZE COAL.

FIG. C—Stoker-fired plant designed for output of 100,000 lb./hr. at 450 lb./sq. in. and 700° F. Fired by mixture of coke breeze and coal together with blast-furnace and coke-oven gas

corresponding back-end gas temperatures it is important to safeguard the back end when the temperatures are down to a low figure, so as not to get unduly near dew-point ; otherwise, although a little extra efficiency may be gained, it may be found that SO_2 or SO_3 will have eaten away the air-heater plates in a very few weeks. There is one forced-draught and one induced-draught fan per unit. Grinding is by Impax pulverizers, with horizontal spindle and exhauster mounted on extension of mill-driving shaft. The star feeder controls the supply to the mills. Automatic control is arranged to regulate the blast-furnace gas with a base load from the pulverized-fuel burners, although air regulation to the solid fuel is available if required. Boiler-load regulators control the air supply to the gas burners, and combustion regulators control the gas supply, while the combustion-chamber suction is maintained by a furnace-pressure regulator.

In the case of a boiler which was designed for an output of 440,000 lb./hr., the final pressure being 448 lb./sq. in. and the temperature 772° F., the final steam temperature is controlled by an interstage attemperator. That really means that instead of putting the attemperator on the superheater outlet it is located halfway down the superheater, so that by taking the temperature up to 680° F., bringing it back to 650° F., and then taking it to the required temperature, overheating the elements at the hot end of the superheater is avoided. The fuel is pulverized coal, supplemented by blast-furnace gas. Corner burners are used for coal firing, with gas burners arranged in the front and rear walls. Oil burners are also located in the corners and are capable of producing 40% of the maximum output. The pulverized-fuel firing is on the bin-and-feeder system, and grinding is by means of Hardinge ball mills. The furnace is completely cooled by fin tubes. The ash hopper is of the open water-cooled type, and the boiler is of the three-drum type with a pendant superheater. There are two air heaters in tandem located behind the steaming economizer.

Figure C is a stoker-fired plant designed for an output of 100,000 lb./hr., with a final steam temperature of 700° F. and a pressure of 450 lb./sq. in. The fuel was to be a mixture of coke breeze and coal, together with blast-furnace gas and coke-oven gas. A limiting factor was imposed by the boilermaker on the firing of solid fuel, which prohibited less than 20% of the evaporation from being obtained on the stoker firing only. In other words, when gas firing is required and the stoker is also to be kept in commission it is

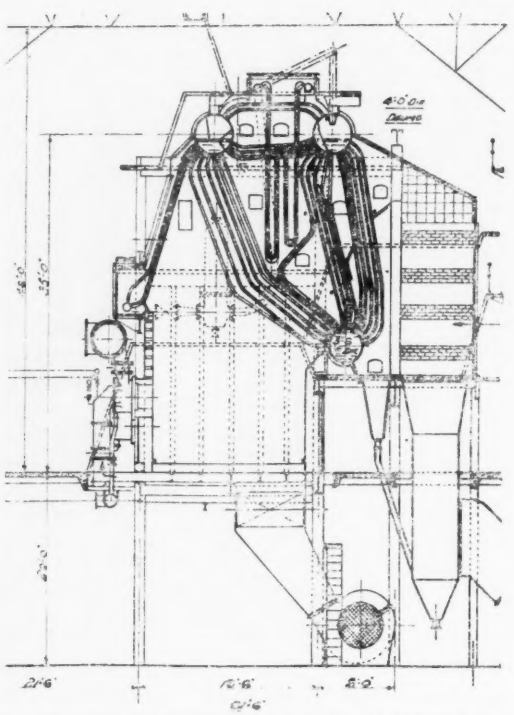


FIG. D—Unit designed to operate at 100,000 lb./hr. at 415 lb./sq. in. and 700° F. Fired by blast-furnace and coke-oven gas with supplementary creosote-pitch firing

necessary to keep the stoker doing about 20% of the load, otherwise there is a tendency to cause mechanical damage to the stoker. If it is desired to go over to 100% gas firing, the grate bars should be protected with about 6 in. of crushed firebrick or by laying tiles on the stoker. The furnace is water-cooled, with refractory blocks on the side walls, and refractory front and rear walls.

Figure D shows units which operate at 100,000 lb./hr. with a pressure of 415 lb./sq. in. and a temperature of 700° F. The fuel is blast-furnace and coke-oven gas, with supplementary creosote–pitch firing. The steam temperature is controlled by an attemperator. The air temperature to the burners is raised by passing the air through the hollow walls, and automatic air/gas ratio control is fitted.

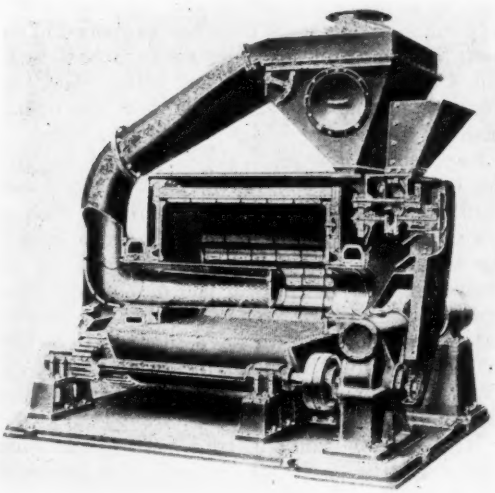


Fig. E—Typical pulverized-fuel ball mill

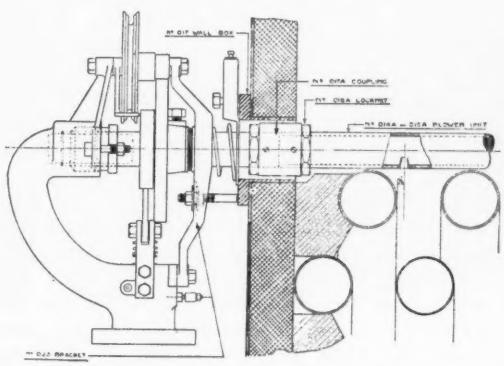


Fig. F—Arrangement of standard soot-blower unit. showing coupling connecting head and blower element, also position of nozzle in relation to tubes

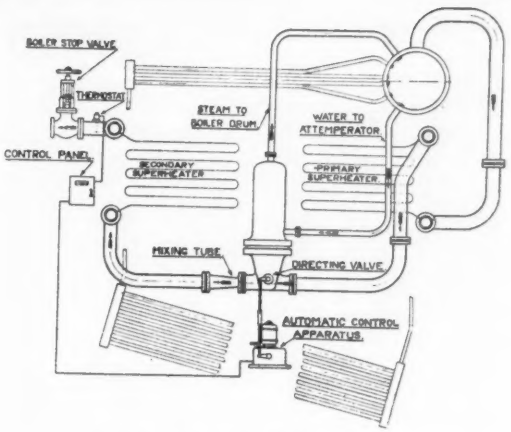


Fig. G—Diagram of attemperator

Figure E shows a typical pulverized-fuel ball mill. The coarse coal comes back to the mill, and the fine coal goes over to the burners. Figure F is an example of soot blowers, and Fig. G is a diagram of an attemperator. By regulating the amount of steam which passes through the tubes, the temperature is reduced at the inlet of the secondary superheater in order to get the temperature required at the outlet of the superheater without raising the temperature in the secondary superheater to an extent that would cause damage to the metal tubes. Figure H shows a typical wagon tippler. If you have to contemplate 100% load on coal for any length of time, you have to put the plant in for full load on coal, although it may have only a few hundred steaming hours per year on coal alone. The boilermaker can be useful here to the steelmaker if brought in at an early stage, and can help to get out the budget figures for a particular plant commensurate with the

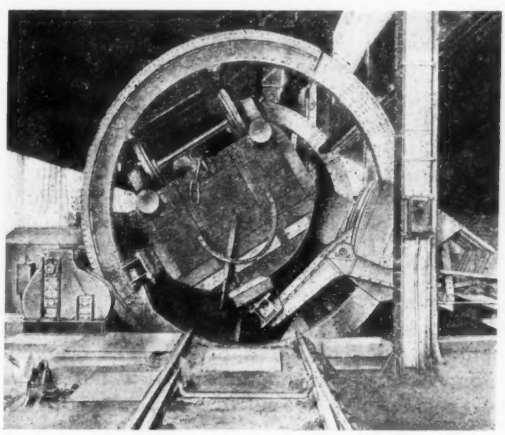


Fig. H—Typical wagon tippler

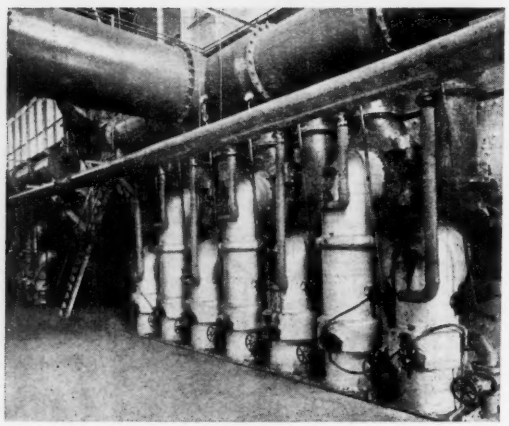


Fig. J—A plant in operation in the north-west of England

load factors which will be imposed on the different kinds of equipment as we go through the details of the cycle which is visualized for the year.

Figure J is a photograph of a plant in operation in the north-west of England. Prior to the installation of these two high-pressure boilers the existing steam plant comprised 29 low-pressure boilers rated at between 8,000 and 19,000 lb./hr., with a total capacity of 300,000 lb./hr., the working pressure being 180 lb./sq. in. at 500° F. When the two new boilers were commissioned, 15 of the old boilers were taken out of commission and shut down. A steam accumulator was installed to compensate for the loss of thermal storage.

I understand that under restricted blast-furnace performance and the attendant disruption of normal thermal balance the average coal consumption on the 29 existing boilers, prior to the commissioning of the new plant, was 578 tons/week. Upon the complete commissioning of the two new boilers and the shutting down of the 15 old boilers, the consumption of coal fell to as low as 170 tons/week, averaged over three weeks' operation, with quite comparable conditions of operation outside the boiler plant. Then came the fuel cuts in February, and the consequent reduction of blast-furnace gas and coke-oven gas has prevented the maintenance of these figures, but in spite of these current difficulties a reduction of 50% in the total solid-fuel intake has been obtained, apart from the coal required for carbonizing.

Creosote–pitch firing, which is the supplementary firing on these boilers, was originally intended as an emergency standby, but is now used regularly as a result of the recent worsening of the fuel situation. I am told that with the installation of additional high-pressure steam-generating plant it will be possible to eliminate the use on all boilers of all solid fuel; the gas which will be used will be surplus to all other works' requirements, and creosote–pitch will revert to its original status of an emergency standby fuel.

The thermal cycle is obviously utterly different in different plants, but our plea is that user and supplier should get together to solve the problems. We on the steam side are just one small factor in this jigsaw. Your problems on the steel side may be even greater than ours, but our point is that we have a range of boiler equipment and supplementary auxiliary equipment which can, we are sure, fill every niche in your cycle. We do not always know all about the cycle, and we often have to work to a specification. We feel that if we knew the answers to some problems external to the steam plant we could sometimes approach the matter from a different angle. Our plea is that we should get together and collaborate at a very much earlier stage than has happened in the past. The contribution which we are able to make will, I think, enable you to buy better plant at a more reasonable cost and then show the overall financial savings for which we are all looking.

I appreciate how much politics are coming into this industry, and some people not far from here think that they can push a button or pass an Act of Parliament and solve all the problems in the industry. The fact that a number of big companies are, in spite of the difficulties, going ahead with major schemes is the greatest encouragement that we have today. I ask you to bring up your problems in the discussion and I will not attempt to guess the questions you have in your minds.

Mr. **I. V. Robinson** (British Electrical and Allied Industries Research Association), who presented the second paper, said : I am presenting this paper on behalf of the members of the Turbine Section of the B.E.A.M.A., which consists of some dozen turbine builders. They are very glad to have the opportunity of bringing to the attention of those engineers concerned with the generation of power in iron and steel works the main features which have been developed over a large number of years and which have resulted in the attainment of such high efficiencies as are obtained in public utility stations. Although I am speaking for twelve turbine builders, and they have all seen a draft of the paper, it must not be assumed that they are all in agreement with everything I say. That is too much to hope for; in fact, I think that I could pick out two firms who would be diametrically opposed on some questions. My views represent a middle way, a compromise, and I put them forward on that basis.

In the large power stations we have been able to develop in many directions to an extent which

is quite impossible in the smaller power stations which are necessarily used in iron and steel works. Further, many of the suggestions which I am putting before you, mainly for criticism, could not be adopted in all stations. Each works would require separate consideration, according to the fuel conditions.

In the central power stations at the present time, the standard pressure for a 30,000-kW. set (almost the smallest now being installed) is 600 lb./sq. in. at 850° F. At this moment there is a meeting at the Ministry of Supply which will probably make it very difficult for power-station engineers to adopt any figures other than 600 lb./sq. in. and 850° F. for a machine of that size. For 50,000–60,000-kW. machines the standard conditions are 900 lb./sq. in. and 900° F., and that also, I think, will be made standard in this country and will be used eventually for all stations. Moreover, a number of stations have gone beyond that ; there are some running at 1250 lb./sq. in. and 1350° F. There is a big gap, therefore, between the steam conditions generally used in iron and steel works power stations and those to which central station engineers have been accustomed for a considerable time.

I should like to mention that standard symbols have been used throughout this paper, and I hope that other writers will do the same.

I think that ultimately we engineers, if we get together, can give you a blower of the axial-flow type which will be eminently satisfactory and which will do the job quite well, but this question will be dealt with very much more completely by Dr. Bowden and others. I do not want the gas-turbine people, however, to assume that they are the only people who can use this more efficient type of compressor which will be discussed this afternoon ; I think that the steam-turbine people should have the benefit of it as well.

Whether you adopt axial flow in place of the present centrifugal is a matter for careful consideration, but if the two sides get together, the blower designers and the blast-furnace engineers, we shall be able to arrive at some satisfactory solution of this apparently difficult point. With regard to item (9) in the Summary at the end of the paper, page 89, I would say that if a large 3000-r.p.m. blower is used, with a geared turbine running at 6000 or 8000 r.p.m., it is easier to use high-pressure steam. If an axial blower is used, the blower speed will be higher, and it may not be necessary to use geared turbines.

Dr. **J. H. Bock** (Messrs. Simon-Carves, Ltd.) : I should like to enlarge upon the remarks made by Mr. Peacock on water-tube boilers as supplied by my firm for iron and steel works.

Figure K shows a boiler built for 45,000 lb./hr., 365 lb./sq. in., and 675° F. The boiler is a three-drum boiler, using blast-furnace gas only, which is burnt by means of a multi-nozzle burner. This installation is of a fairly early date, but already includes an economizer and air heater in order not only to give a high efficiency but also to ensure the burning of the blast-furnace gas which, from our experience, is inclined to be a lazy gas owing to its low calorific value and to the high content of nitrogen. The inclusion of an air heater ensures the complete burning-out at different loads.

Figure L shows a boiler installation at the works of the Shelton Iron, Steel & Coal Co., Ltd. This boiler is arranged for firing blast-furnace gas and pulverized fuel, either together or separately.

The burners used for the blast-furnace gas are again of the multi-nozzle type. The pulverized fuel is supplied by a unit-type pulverizer arranged for air drying in the pulverizer itself, which enables it to handle coal with up to 18% of moisture. This boiler was installed in the early years of the war and incorporates several features which hitherto were used only in power-station practice, *i.e.*, a completely water-cooled combustion chamber having a hoppered bottom, with a continuous low-pressure water-sluicing system.

This boiler is designed for 450 lb./sq. in. and 420° C. (788° F.) steam temperature leaving the superheater.

In order to have a relatively high air temperature for drying the coal when pulverized fuel is fired, no economizer is included, but the boiler was provided with a " MeLeSco " superheater manufactured by the Superheater Co., Ltd.

As mentioned by Mr. Peacock and in the paper, there is a considerable difference between the quantities of waste gases for the same duty. If, however, one compares the figures actually obtained in practice when considering the air excess, the difference for the same duty expressed in percentage between pulverized fuel and blast-furnace gas is 67% to 100%.

Mr. Peacock also mentioned—as does the paper—that the gas weights with pulverized fuel and with blast-furnace gas differ considerably for the same evaporation, and allowing for excess air the ratio is 67 : 100 respectively. Therefore, much higher superheat obtains with blast-furnace-gas firing and to maintain constant superheat with both fuels and over a range of loads, controlled-type superheaters were provided.

The required steam temperature to the extent of 20° C. at the lowest load was not obtained on pulverized-fuel firing, and it was evident from the low gas temperature measured at the superheater outlet that it was of little use increasing superheater surface.

Since it was not desired to reduce the boiler convection surface in front of the superheater or

to reduce the heat absorption in the furnace, the Superheater Co., Ltd., proposed that gas recirculation from the air-heater outlet to the furnace be adopted, thereby increasing the gas weight passing over the superheater surface.

Gas recirculation was easy to arrange, since the fans were capable of dealing with the larger volumes, which were approximately equal to those to be handled when using blast-furnace gas. It was necessary to provide a return duct from the pressure side of the I.D. fan to the base of the furnace and dampers to regulate the gas flow.

We would like, at this point, to thank the Shelton Iron, Steel & Coal Co., Ltd., and the Superheater Co., Ltd., for the kind help they gave us in solving this difficulty.

Figure M shows the recirculation duct as adopted for the Shelton installation. This method has proved so successful that we have used it on a later installation.

Extensive tests were made at the Shelton plant in order to ascertain the gas quantities, etc., when using pulverized fuel and gas recirculation.

Figure N shows the results obtained by the recirculation tests, the two top curves giving the efficiency with and without recirculation, on pulverized fuel, the curve below showing the percentage of the products recirculated, and the bottom curve showing the gas temperature leaving the air heater.

In order to obtain the gas quantities, the area of the duct was divided into 16 equi-rectangles and in the centre of each rectangle the velocity was measured by means of a pitôt tube. To obtain the velocities more accurately, contour lines of $\sqrt{h}$ were drawn as shown in Fig. O and

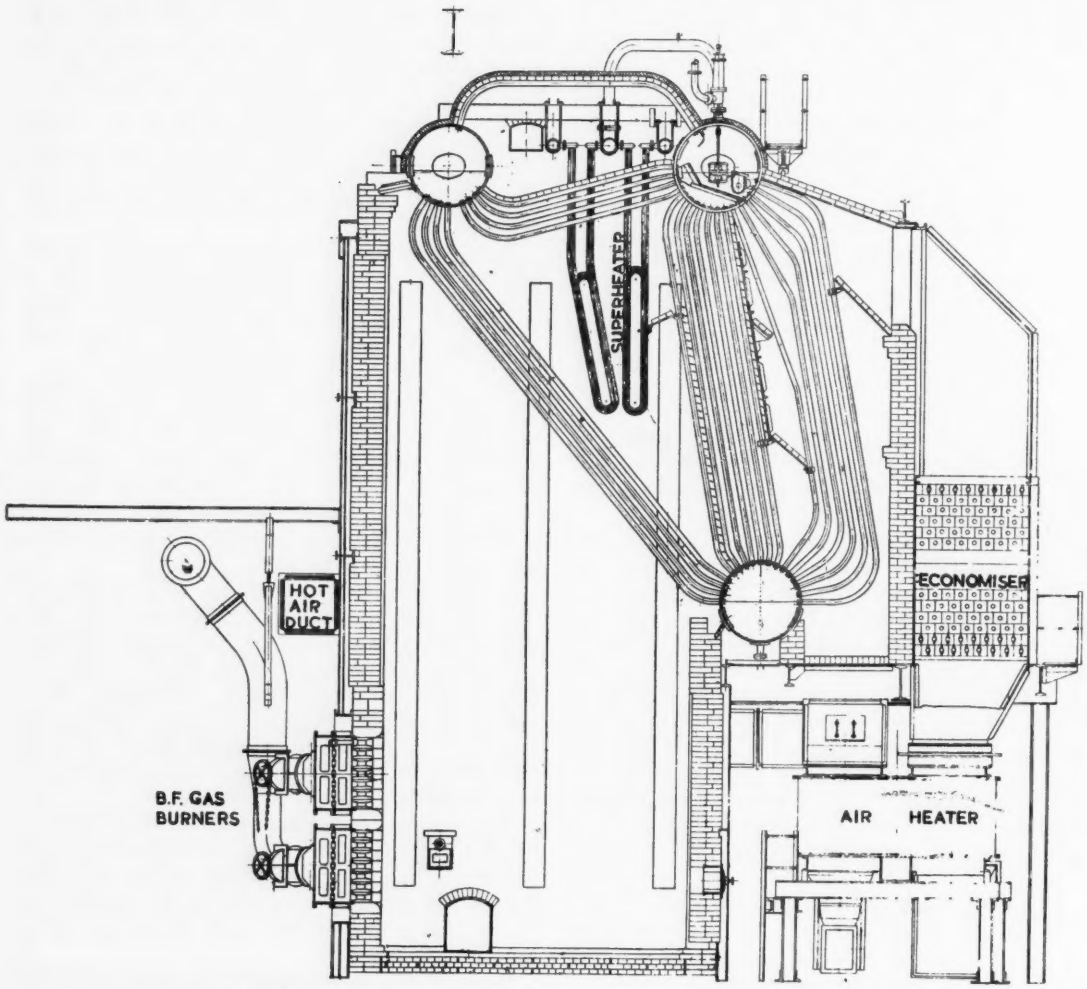


FIG. K—Boiler built for 45,000 lb./hr., 365 lb./sq. in., and 675° F.

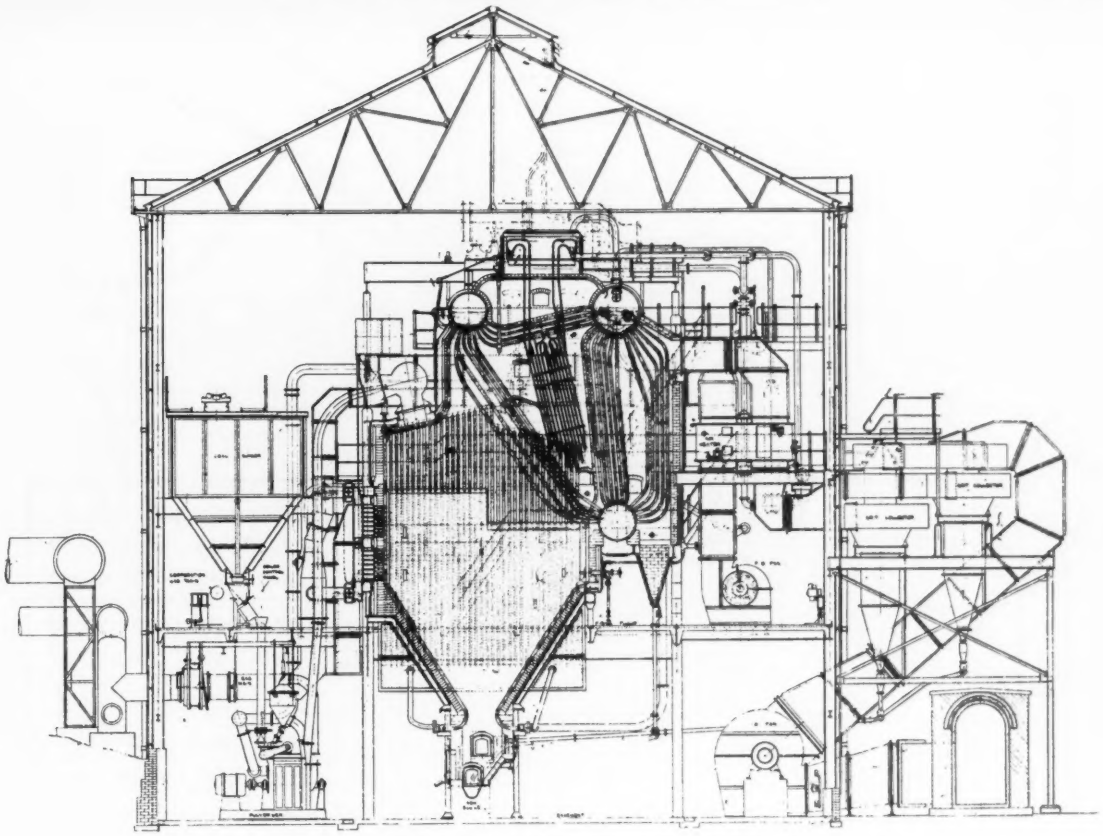


FIG. L—Boiler installation at the Shelton Iron, Steel & Coal Co., Ltd.

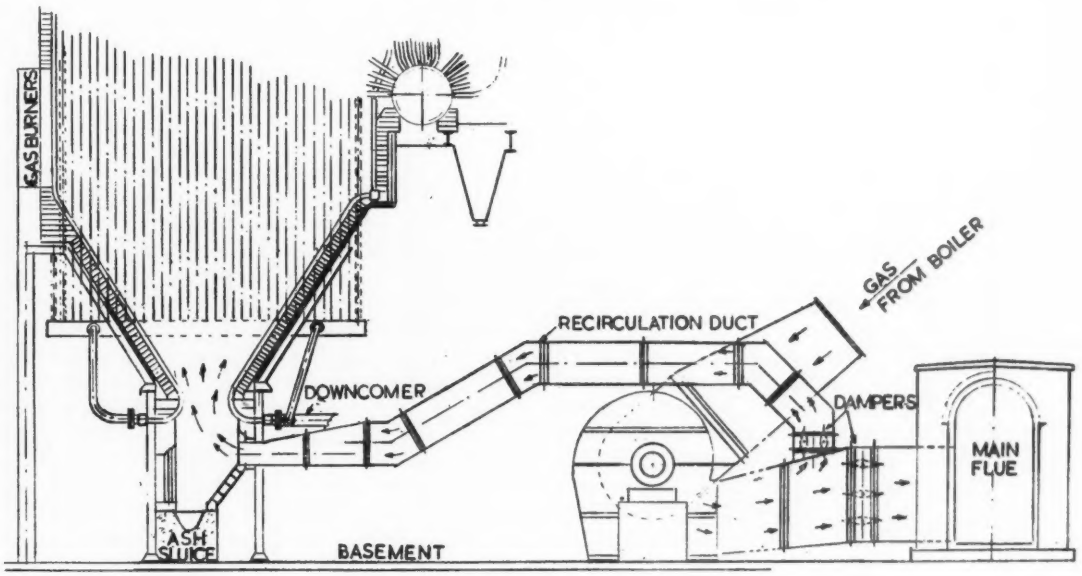


FIG. M—Layout of recirculation duct

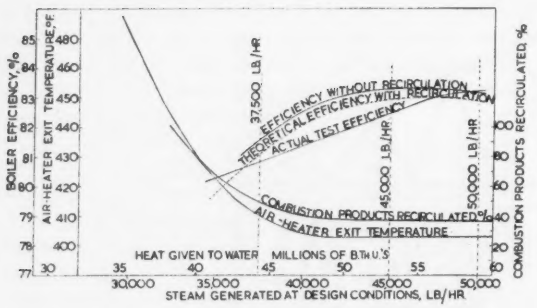


FIG. N—Results of recirculation tests (Shelton No. 2 boiler)

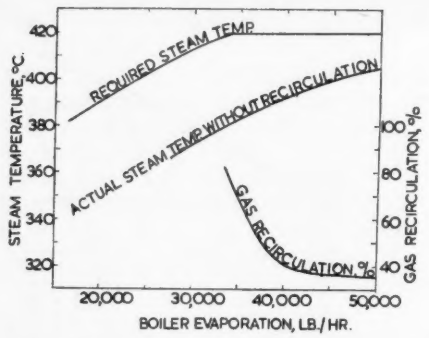
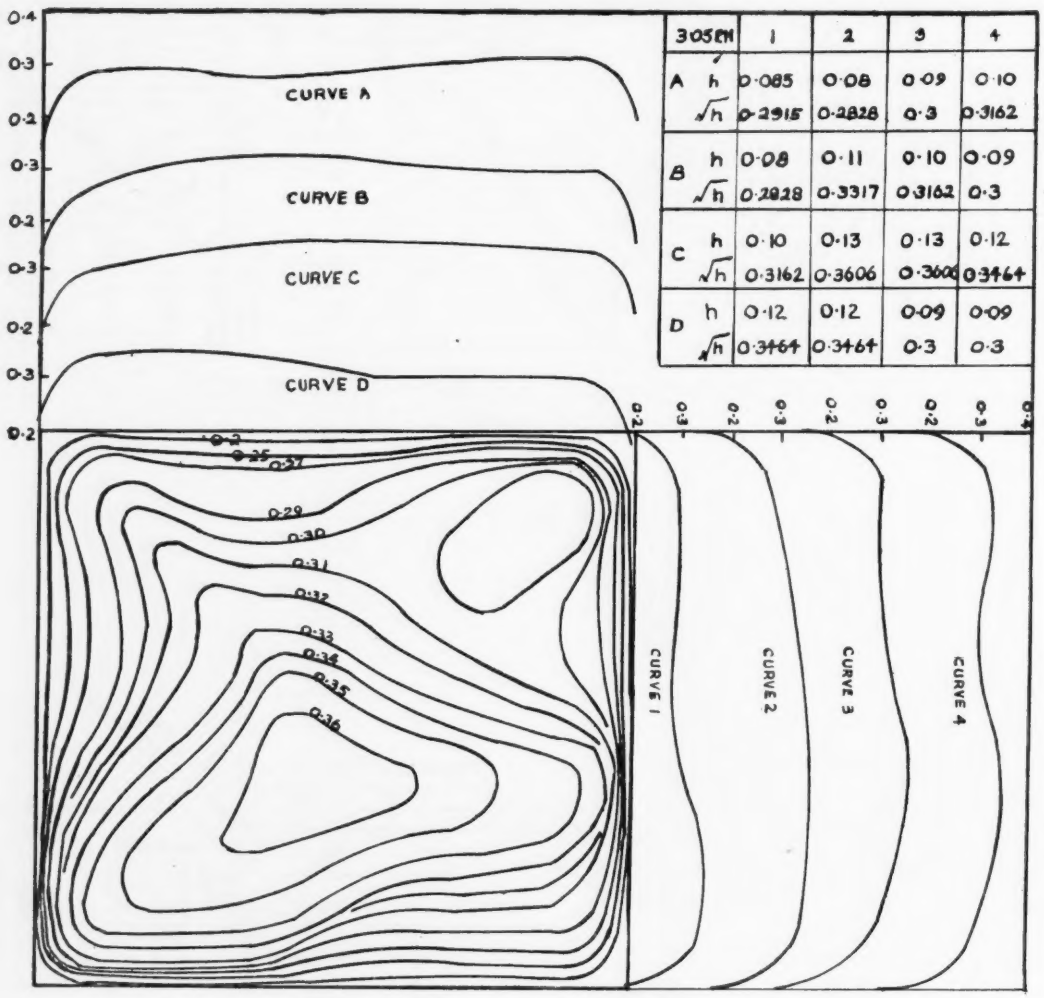


FIG. P—Temperatures obtained at various loads, with and without recirculation



30 SEC		1	2	3	4
A	h	0·085	0·08	0·09	0·10
	√h	0·2915	0·2828	0·3	0·3162
B	h	0·08	0·11	0·10	0·09
	√h	0·2828	0·3317	0·3162	0·3
C	h	0·10	0·13	0·13	0·12
	√h	0·3162	0·3606	0·3606	0·3464
D	h	0·12	0·12	0·09	0·09
	√h	0·3464	0·3464	0·3	0·3

FIG. O—Velocity-head graph for recirculation duct (Shelton No. 2 boiler)

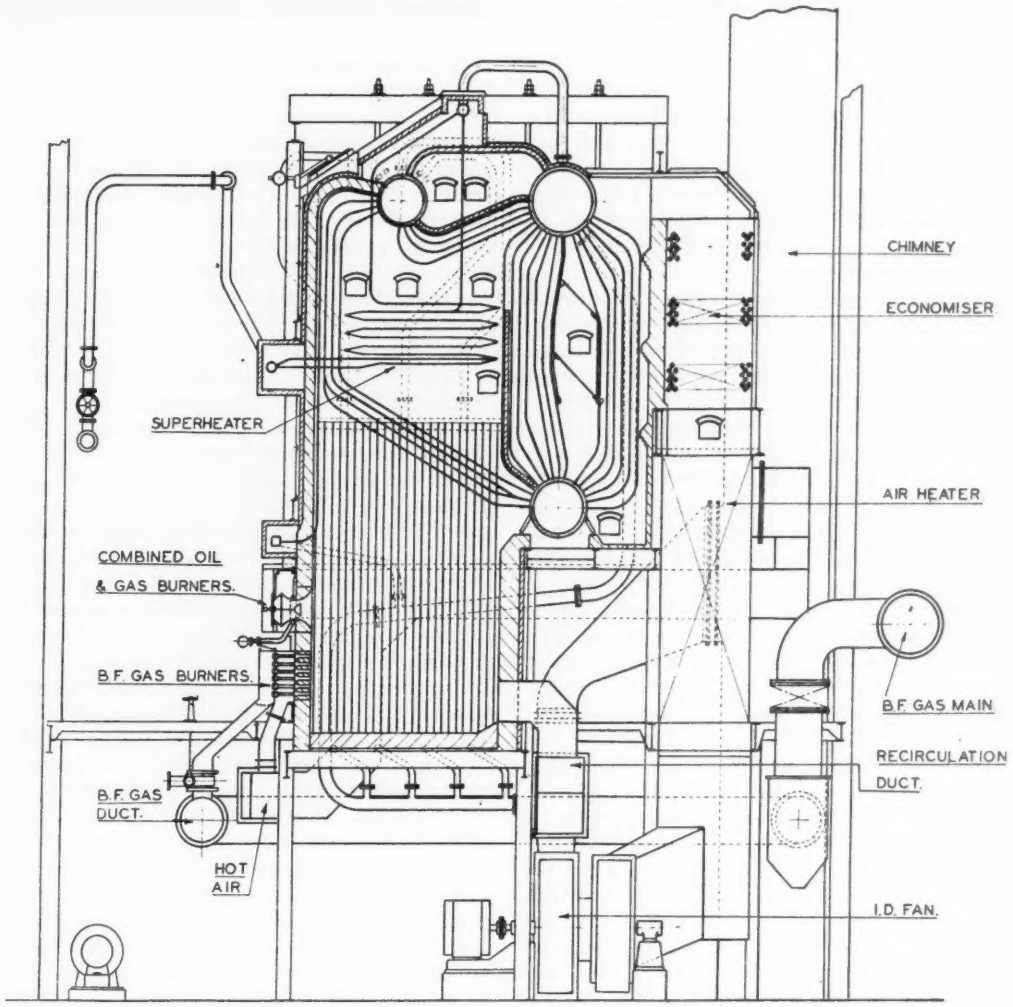


FIG. Q—Layout of boiler to be installed in a South Wales steelworks

the areas were measured by a planimeter.

Figure P shows the temperatures obtained at different loads with and without recirculation.

In Fig. Q is shown a modern boiler which will be one of a group of four to be installed in a big steelworks in South Wales with modern pressures and temperatures. These boilers are based mainly on the firing of blast-furnace gas, but in addition to this coke-oven gas and oil as auxiliary fuels can be used. Each boiler is designed for 87,000 lb./hr. evaporation, 630 lb./sq. in. pressure, and 820° F. at the superheater stop valve. The blast-furnace gas burners are again of the multi-nozzle type, and for the coke-oven-gas and oil firing a combined burner is adopted. In order to keep the superheat constant, gas recirculation has been adopted, based on the experiences gained on the Shelton boiler.

The superheater is of the self-draining horizontal type, a feature which is used in modern power-station practice.

The economizer is of the steaming type, and the air heater of the tubular type. The efficiency on blast-furnace gas at 87,000 lb./hr. evaporation will be 84·5%.

From this it will be seen that it is possible on a modern boiler plant to adopt features which hitherto would not have been considered worth while, and therefore boilers of such a design compare favourably in efficiency and reliability with boilers of far larger capacity used in modern power stations.

As Mr. Peacock mentioned, if we are called in at an early stage we not only design boilers to suit the conditions for the plant concerned, but also give efficiencies with blast-furnace gas which

would not have been thought possible several years ago.

Mr. **F. Kennedy** (Messrs. Dorman, Long and Co., Ltd.) : I wish to thank the authors for two very interesting papers, and regret that they were not presented two or three years earlier when we were examining these very problems in connection with our works developments ; a brief résumé of the decisions then reached and the reasons for them may be of interest.

Boilers.—The units installed have a normal economic rating of 100,000 lb./hr., and a maximum continuous rating of 125,000 lb./hr. at 450 lb./sq. in. pressure and 725° F. ; they are arranged for blast-furnace-gas and mixed coal-and-coke-breeze firing on the sandwich, or rather, layer system. For technical reasons pulverized-coal firing would have been preferred, but our coke ovens produce large quantities of coke breeze which in normal times were disposed of at an uneconomic price and stokers were therefore installed to utilize this low-grade material.

The choice of 450 lb./sq. in. boiler pressure was influenced by a certain amount of existing equipment ; otherwise, a pressure of approximately 650 lb./sq. in. would probably have been chosen.

Both air heaters and economizers are fitted, and at this point I should like to ask a question and also join issue with the authors of the boiler paper who talk about blast-furnace gas as a cheap by-product. Most operators in an integrated works consider the blast-furnace gas a gasified fuel of much greater value on a thermal basis than the normal cheapest grades of boiler coal available at the present time. (The main objection is the cost of suitable and adequate storage capacity for large volumes of low-calorific-value gas.) The most efficient utilization should, therefore, always be aimed for in the steelworks and the gaining of a few extra per cent efficiency is worth a considerable expenditure ; in this connection I should be pleased to have Mr. Peacock's views regarding the installation of a gas heater in addition to the air heater, particularly in those cases where bled steam is used for feed heating and the amount of work which can be done by the economizer is reduced. There is a general tendency in the papers to under-estimate blast-furnace gas, which is a very valuable fuel and in an integrated steelworks must be efficiently utilized.

Reverting to our own boiler plant, every care has been taken to ensure the minimum outage time of the boiler by careful attention to ensure that both water and gas sides of the boiler heating surface are kept as free from deposit as possible ; extensive water-treatment plant has been fitted and to maintain optimum cleanliness of the gas side of the heating surfaces, an outfit of remote-controlled, automatic sequence soot blowers is included.

We considered heat-distribution schemes similar to those put forward in Mr. Robinson's paper and our final arrangement (which again was influenced by existing equipment) was that on the steam-utilization side the bulk of the 450 lb./sq. in. of steam will be used in straight condensing sets, *i.e.*, one 10,000-kW. turbo-generator, one 7,500-kW. turbo-generator, two 48,000-cu.ft./min. turbo-blowers, and one 80,000-cu.ft./min. turbo-blower. We are also installing one 6,000-kW. pass-out set arranged for the passing out of up to 150,000 lb./hr. of steam at approximately 135 lb./sq. in. pressure for process purposes, etc., and a smaller amount of steam at 15 lb./sq. in. pressure for de-aerating additions to the turbo-blowers are now being further considered.

Mr. Robinson's suggestion of back-pressure turbines for blowers would probably lead to uneconomic operation at weekends when electrical load is shed owing to mills being idle, and would also tend to lack of flexibility during the normal working week when, for various reasons, blast-volume requirements of the furnaces may be reduced, but the demand for electrical power by the mills is at a maximum. Efficient and economic operation of an integrated iron and steel works demands that production in all departments should be kept at a maximum, but if the power available for the mills were likely to be limited by troubles or stoppages at the blast-furnaces, efficiency would suffer, and therefore, whilst agreeing with Mr. Robinson on the desirability of utilizing the steam at as high a pressure and temperature as possible, this can and should be arranged without unnecessarily inter-linking the operation of entirely different sections of the works ; pass-out sets with automatic control of the amount of passed-out steam to suit works demand for low-pressure steam is more likely to suit steelworks conditions than the simple back-pressure set.

The decision regarding what steam temperatures and pressures should be installed must take into consideration both technical and economical considerations, and a preliminary idea of costs would be of the greatest value when plant alterations are being considered, particularly during these critical times when contractors, and drawing and estimating offices are overwhelmed with work and do not look favourably upon supplying definite prices for various alternative schemes which are not necessarily bound to materialize. It would greatly add to the value of the papers to the engineering staffs of iron and steel works if the authors would give an idea of the relative capital expenditure required for plant, *i.e.*, in the case of boilers, express as a percentage the capital cost of a 100,000-lb./hr. boiler, for operating steam

pressures of 200, 400, 600, and 800 lb./sq. in. Similarly for turbo-alternators, the relative capital cost should be given of the units for a similar range of pressures, condensing and alternatively passing-out at, say, 120 lb./sq. in.

It will be noted from the foregoing remarks regarding steam utilization that before the end of the year we anticipate having in commission five turbines taking steam at 425 lb./sq. in. pressure, and an 80,000-cu. ft./min. turbo-blower is due for delivery next year. It is suggested, therefore, that in view of the number of units using steam at a higher pressure which we have in mind, there must be some error in Mr. Robinson's statistics regarding the numbers of turbines using steam at over 400 lb./sq. in. pressure in commission in the iron and steel industry.

Will Mr. Robinson give an indication of the relative overall efficiency of the geared turbo-blower delivering 80,000 cu. ft./min. with a turbine speed of 6000 r.p.m. as compared with a direct-coupled unit running at 3000 r.p.m.

Will Mr. Peacock state what is the maximum percentage of coke breeze that can be burnt on their stokers with the extended back arch, and what is the combustible in the boiler ashes.

Mr. **Peacock** : In reply to Mr. Kennedy, dealing first with the question of air heaters, it is difficult to have any preconceived ideas as to whether an air heater should or should not go in, but what would influence me, and I think all boilermakers, would be, first, the condition of the blast-furnace gas, whether it was reasonably clean or very dirty, so as to get some idea of the degree of availability of the air heater, particularly if of the Ljungstrom type, from the point of view of continuity of service. Again, we should be influenced by the feed-water temperature to the economizer. I agree that the tendency today is to get higher feeds, but where the feed is fairly low and we can get a final gas temperature with a fairly big economizer down to 380°, 390°, or 400° F., there would not be a strong case for putting in an air heater, based on purely economic grounds of capital cost. It may bring down the gas temperature only another 50 or 60° F., making only 2% difference in efficiency, for a substantially increased cost due to the heater and ducting. On the other hand, if the feed-water temperature is fairly high—250° or 300° F., or higher, as the tendency is today—the gas temperature leaving the economizer would mean that you could not help getting exit temperatures in the region of 450° F., and to put 450° F. up the stack would be a crime in these days. In such circumstances the installation of an air heater would be warranted and would make for an increase in the efficiency of anything from 6 to 9%, depending on the initial inlet gas temperature.

The extra power consumption with blast-furnace gas has to be taken into account. There is the difference in volume, which has given so much trouble on superheat, but it also influences the draught plant ; the induced-draught fans have to be designed to handle the full load with blast-furnace gas, and on switching over to 100% oil fuel the volume is entirely different. There may be special motors—two-speed or commutator-type motors. With the ordinary, inexpensive squirrel-cage motor a good deal of power is wasted. When the air heater goes in the circuit you have to compensate for the draught loss of the air heater, and if the air heater is going to give only a 50–60° F. drop in back-end temperature there will not be such a good economic case for it as when the higher feed-water temperature permits the air heater to give an increase in efficiency of 6–8%. My own view is that air heaters should be in whenever the feed-water conditions to the economizer justify it, but do not let us put in an air heater as an ornament if it cannot be justified on economic grounds.

On the question of prices, I can assure Mr. Kennedy that on any specific plant any boiler-maker would without loss of time give percentages for various pressures, provided that we were talking about the same kind of plant. I think the reluctance of any technician to put in a paper the relative increase in prices is due to a great extent to the fear that such information might be misconstrued and taken as applying to the whole range of boiler plant. If, on the other hand, a certain plant is considered where the fuel conditions are known, we can visualize the type of boiler plant which we should put in, with or without economizer plus the various auxiliaries, and the varying percentages can be assessed quite easily and be within 1 or 2% of the mark. This reinforces the plea which I made for early and complete collaboration between us, so that such information can be given in the early days, in order that the steelplant engineer can have alternatives worked out and crystallize his ideas.

With regard to coke breeze, I can safely give the assurance that 100% coke breeze can be burnt on a stoker-fired plant satisfactorily. In the past, in some of the earlier jobs, there may have been limitations imposed as to how much coke breeze should be used ; but there are many jobs, particularly in gasworks, where a wide range of coke breezes has been burnt, and where 100% coke breeze with very small sizing and very low volatile contents has been burnt with very good results, with high efficiency and comparatively low carbon-in-ash loss. The condition which we do impose is that when burning any solid fuel on a stoker with a gaseous fuel, care must be taken

not to leave the stoker bare when burning blast-furnace or any other gas. If protected it is satisfactory and blast-furnace gas can be burnt. As a guide 20% of the evaporation which should be obtained by the stoker is taken. An archless setting can be put in with a reasonably long rear arch and 100% coke breeze can be burnt.

Carbon in ash is a function of the ash content in the fuel as received. If there is only 10% of ash in the fuel, then I should not expect to find more than 10% of carbon in the ash ; but as the ash content of the fuel goes up, so the carbon loss in the fuel may vary as the square, because it is obvious that it is much more difficult to burn all the carbon in the solid fuel with 35% of ash than with 10% of ash.

I think that my co-authors would like me to say that if we have created the impression that we regard blast-furnace gas as a cheap fuel we have done so inadvertently ; we did not mean it. We have regarded it as the common or basic fuel for the steel industry, but anything that has thermal units in it is never regarded by us as something to be wasted. We want to use every possible thermal unit in every fuel economically ; this is the boilermaker's approach to the problem.

Mr. **Robinson** : Mr. Kennedy made the remark that back-pressure turbines driving blowers would be uneconomical at the weekend. They could be made into pass-out turbines, and all the steam could be passed out except the small quantity required to keep the low-pressure end of the turbine cool. If the power turbine did not require so much power at weekends, it could be run as a straight condensing turbine.

Mr. Peacock has referred to the variation of price for some standard units with different pressures. It is quite possible to give such information, but the danger is that too much weight might be attached to such figures. If given, they should be interpreted strictly in accordance with the information upon which they were based. But it could be done, and I have seen such figures.

Mr. Kennedy questions the data which I have given with regard to plant in iron and steel stations. I admit that they are not complete, and I did discover after I had prepared those figures that there were some other plants working at over 400 lb./sq. in. I will look into the matter and see whether I can make the necessary corrections.

Mr. **N. H. Turner** (Appleby-Frodingham Steel Co., Ltd.) : I should like to limit my remarks to a few questions mainly in connection with the paper on boilers, but first I would endorse what Mr. Kennedy has said about the usefulness of having some indication of cost. Whilst we appreciate Mr. Peacock's answer, I still feel that such information would be very useful, especially if the effect of the operating pressure on costs is added to that of the output.

The authors claim that water-tube boilers can deal more satisfactorily with blast-furnace and coke-oven gas than shell boilers. I do not understand that, nor do I understand why later on they claim that the utilization of waste heat presents no problem to the boiler designer. As users of waste-heat boilers, we hold an opinion which is different from that, and we feel that sometimes the boiler designers should pay more attention to such a question.

The paper states " Creosote–pitch can also be utilized in the same way as oil fuel, providing suitable atomizing equipment is installed." What is the point there ? In what way is the atomizing equipment for creosote–pitch to be different from that for oil ? Creosote–pitch may be a little more abrasive, but apart from that I should have thought that it was more a question of suitable viscosity.

The authors also say " It is perhaps more important that it (blast-furnace gas) should be cool and dry than clean." Again I fail to understand the point. There is mention later in the paper of " clean " gas which has been cleaned by wet washing followed by further cleaning in a precipitator, and which still contains 0·6 grains/cu. ft. of dust, and it is said that that has been a cause of trouble with the tubes. I would not call that a clean gas. We have used clean gas on water-tube boilers for a long time, and we operate a boiler for at least one year at a time without having to clean the outside of the tubes ; in other words, we have no deposition worth mentioning. Some of our boilers use gas which is appreciably warm, and others use gas relatively cold. On none of them do we have any trouble.

Mr. **Peacock** : Is it wet ?

Mr. **Turner** : I am referring to gas coming out of a wet cleaning plant for one group of boilers and to gas cleaned in a dry cleaning plant for other groups.

The authors make the statement that the combustion of a correctly proportioned mixture of blast-furnace gas and air is instantaneous. I think that is far from being fully correct. Blast-furnace gas is a slow-burning gas, and that is one of the reasons why it has been found necessary to have a large combustion chamber when using it.

I should like to know whether Mr. Peacock considers that it would be logical, when a shortage of blast-furnace gas occurs, simply to reduce the blast-furnace gas to a certain proportion and to make up the difference with pulverized fuel or stoker-fired fuel, or whether he would prefer to have the boiler entirely fired with one fuel or the other. If the boiler is entirely fired with one fuel,

I do not see the point of his remark about the CO_2 measurement, because it is simply a matter of the CO_2 which has to be accepted for the given fuel. While I have nothing against the measurement of oxygen, I still feel that CO_2 instruments can continue to be used, in spite of the fact that two different fuels are being employed.

I do not follow the argument for the necessity of two forced-draught fans, except perhaps for very large boilers. We have boilers operating on pulverized fuel and blast-furnace gas with only one forced-draught fan, and we have no difficulty whatever.

Mr. **Peacock** : With full automatic control ?

Mr. **Turner** : No, only on blast-furnace gas.

As far as automatic control is concerned, I do not know what advantage Mr. Peacock would expect from automatic control on a boiler used in connection with a reversing mill, as there would be very many disadvantages if the control tried to follow the rapid fluctuations which are bound to take place.

There is a remark in the paper about dust emission in steelworks not being material. I think that the authors will find that the tendency now is to pay attention to such things as that and to try to make the steelworks as clean as anywhere else.

Mr. **A. Bridge** (Appleby-Frodingham Steel Co., Ltd.) : I would like, in the first place, to refer to the paper which has been presented by Mr. Robinson. On page 82 it is mentioned that for units of 20,000 kW. and below, a steam pressure of 400 lb./sq. in. and a total temperature of 800° F. is standard practice. Could Mr. Robinson give the optimum pressures and temperatures for various sizes of turbo-alternators ? Such information would be of great assistance to all iron and steel works engineers.

On page 83, under the heading " Condensers," there is mention of the provision of suitably hinged doors at each end of the condenser, so that one half of the condenser could be cleaned while the turbine was in operation on reduced load, but I have not yet met any engineer who has ever tried this out. I do not know why, except that I should imagine that it requires a good deal of courage to clean half a condenser while the turbine is running. Perhaps Mr. Robinson would say what are the hazards, because I notice that he goes on to say that such facilities are not often used. Personally I have never had the courage to try it.

On page 86, the question of working two turbines in series is dealt with. Like Mr. Kennedy, I am a little scared of that. I think that the blast-furnace manager would not welcome an additional hazard to his furnace blowing by having a generator in series to a turbo-blower. On the other hand, I do not think that the mill manager would like to find that power was off because of some maintenance problem on the turbo-blower. Further, I think that the prime considerations with any turbo-blower are reliability and flexibility. With a turbo-blower working in series with a turbo-generator, I feel very strongly that the turbo-blower condenser should be driven from a separate electric supply to that from the generator which it is feeding, otherwise if you lost your generator on a trip-out, you would lose your blower too, or be forced to work on a reduced output, until you could regain vacuum, which is not always a quick job. Another point with regard to turbo-blowers is that we should bear in mind the possibility of requiring volumes of 80,000 cu. ft./min. at about 30 lb./sq. in. pressure in the future, and those figures are higher than those of the machines mentioned in the paper.

My final point about running the two machines in series (apart from the fact that there are times when it would undoubtedly be uneconomical) is to disagree with Mr. Robinson's suggestion that the blower should be the first machine, and the generator the second. Why ? Surely if you are to run the two machines in series, the generator should be first, because of the constant-speed and steady-load conditions, while on the other hand the blower load will fluctuate according to operational conditions at the furnace.

With reference to the paper which Mr. Peacock has presented, and which I found very interesting and informative, I have not many comments to make, but there is one question which I should like to ask, and that is with regard to the use of high temperatures. What troubles are being experienced with regard to valve spindles sticking ? Are they really serious on the boiler side ? I know that troubles of that kind do occur with high temperatures on turbines, because I have had turbine control valves stick when working in the region of 780° F. ; but what happens at higher temperatures ?

I am rather annoyed to find that the authors think that dust emission does not matter in an iron and steel works. I hope that their remarks will not be taken seriously, because dust in an iron and steel works *does* matter. It is one of the engineer's biggest enemies, and I for one should like to see precipitators installed in all future pulverized-fuel plants.

As far as the fully automatic control of blast-furnace gas is concerned, I strongly recommend that a by-pass pilot be fitted, so that if the gas is shut off quickly, owing to a trip-out somewhere, it is not followed by a kick in the combustion chamber when the gas supply is automatically restored. We have experienced such an occurrence, and it happened so quickly that the boiler-

man had no time to shut off his valves. The gas did not ignite until it caught a hot-spot in the boiler, with the result that all the tiles were blown off the top of the combustion chamber. Therefore I consider that a by-pass should be fitted in all cases of fully automatic gas control.

The **President** (Dr. C. H. Desch, F.R.S.) : Mr. Robinson referred to a diagram such as Fig. 1 on page 85, with the various symbols for machines of different types. Is the British Standards Institution dealing with that point ?

Mr. **Robinson** : It has dealt with it. The standard has been issued already.

The **President** : Obviously we need standard symbols. Allied to that is the question of the temperature scale. At these meetings of engineers, most people talk about Fahrenheit temperatures, although one speaker this morning used centigrade. I wish that we could come to an agreement about that. On the metallurgical side, the use of centigrade is almost invariable. It is the international rule, and it is used in all scientific work. Those of us to whom Fahrenheit is unfamiliar have to keep doing little mental sums to find out what these temperatures really mean. That applies, I think, to most scientific metallurgists.

Another point is that anyone who is interested in the question of the conservation of energy must always be horrified by the sight of cooling towers dissipating such an enormous quantity of heat. I wonder how far engineers in these industries are considering the possible means of utilizing low-grade heat ? There has been a good deal of discussion of it recently, and we have heard some remarkable stories of what has been done in other countries. The amount of heat which is wasted in that way is very large indeed, and, although thermodynamically it is a difficult problem, solutions have been suggested.

Mr. **A. F. Webber** (Messrs. A. F. Webber, Ltd., Birmingham) : My professional practice now lies in spheres of steam generation and utilization in general industry rather than in the steel industry, but I had eight years on these problems, and in fact the first paper that I ever presented to any technical institution was a paper to this Institute in 1932 on the generation of steam from blast-furnace gas. I have been surprised by the fact that in a session concerned with power generation in the iron and steel industry it is not considered necessary to pay any attention to the reciprocating gas engine. In the paper which I wrote fifteen years ago I hazarded the opinion that if at that time the gas engine had not ousted the turbine, with turbines working at 160 lb./sq. in. and 550° F., it would hardly do so in the future, since there was far more scope for the development of the efficiency of the steam cycle than there was of the gas engine. I do not think that there has been any improvement in the overall efficiency of the gas engine since then.

With regard to Dr. Desch's remarks about the use of temperature scales, at the first meeting of the British Standards Committee on technical units and data, with Dr. E. W. (now Sir Ernest) Smith in the chair, I put in a plea that the B.S.I. should take a firm line and recommend the centigrade scale throughout. I believed then, and I still believe, that the attachment of British engineers to the Fahrenheit scale is largely imaginary, and that if a firm lead were given for a universal adoption of the centigrade scale it would be followed much more readily than most people believe.

On the question of the cost of blast-furnace gas, the authors of the first paper have committed themselves to the statement that as it is a cheap by-product a few per cent in efficiency do not matter. That applies only, however, where there is, as in merchant blast-furnace plants, a continued surplus of blast-furnace gas. If by improving the efficiency of its utilization more steam can be produced from the amount of gas available, and therefore less coal need be burnt to make up, it is the price of the coal which justifies the economy, not any figure which may be put on the gas. Mr. Kennedy said that blast-furnace gas was more valuable than the ordinary cheap boiler fuels. If he can tell me where any cheap boiler fuels are to be obtained, I have half-a-dozen clients who would quiver with excitement. Those days have gone.

On the subject of the cleaning of blast-furnace gas, I was interested in what Mr. Peacock said about the disadvantages of partial cleaning. I formed the opinion that probably the worst thing to do for blast-furnace gas for boilers was the old rough cleaning. The gas was not thoroughly cleaned ; its sensible heat, which is not inappreciable, was lost, and though by cooling it the moisture in saturation was reduced, in many cases it was left loaded up with a water mist which had to be evaporated in the furnace.

Mr. Kennedy referred to the preheating of the gas. I should like to approach that from another point of view, not merely as a question of getting the heat out of the waste gases and whether it is better to do that purely in the economizer, or by air heating as well, or possibly by gas heating. I prefer to look at it from the point of view of improving the furnace conditions. The real trouble with blast-furnace gas, even after it has been cleaned, is the very low calorific value, and hence the low furnace temperatures. The air which we put in is 80% inert, and the fuel 70%. Anything which could be done to upgrade the

furnace conditions would be of very great value. If the gas after cleaning and cooling is then preheated, so that hot, dry, clean gas is put in as well as hot, dry, clean air, I think there will be very great advantages. First of all, it would reduce the disproportion in the operating conditions between blast-furnace-gas firing and the supplementary fuel, since the extra heat put in in this way would not lead to an extra quantity of products of combustion.

It will also have advantages as regards the heater design. One of the troubles with air-heater design for boilers fired with blast-furnace gas is that the volume of flue gas is about twice that of the air being heated, so that the temperature fall is only half the temperature rise of the preheated air. That rapidly leads to a totally inadequate temperature difference between gas and air at the hot end of the heater. If, however, the gas stream is split, and half is put through the air heater and half through the gas heater, the quantities on either side of each heater are about the same, and a much better temperature difference is obtained. I feel that that is a direction along which there is real scope for investigation.

Mr. Peacock, in referring to fan control and the various methods of speed control, did not mention at all what is, I suppose, the most usual one, *i.e.*, the slip-ring motor with rotor regulation. That is a most inefficient method for a constant-torque machine. If a 10% speed drop on a constant-torque drive is wanted, 10% of the power has to be wasted in the rotor resistance, and the other 90% goes to the machine. With a fan, however, the torque falls off very rapidly indeed when the speed is dropped, and therefore it is not nearly such an inefficient method of controlling the speed.

Some two or three years ago, I had to look into the question of fan design for an installation, not a very large one, with full-load evaporation of 60,000 lb./hr. going down to an assumed lower load of 40,000 lb./hr. I had tenders for almost every combination of fan and motor imaginable—single speed, squirrel-cage with hydraulic coupling and two speeds, slip-ring motor with rotor speed control, and so on. They were all just about the same in first cost and in power consumption at the lower load, which was rather a surprise to me. I thought that the decision which I should have to make would be whether the improved efficiency of these other methods of control at the lower load was worth the extra cost, but there was not much extra cost and there was not much improved efficiency. I think that if fans are not very large there is still a case for rotor resistance control.

Mr. **G. W. Lake** (Shelton Iron, Steel & Coal Co., Ltd.) : I wish to express my appreciation of Mr. Peacock's paper, which is very concise and lucid. However, from the point of view of an operator of typical steelworks boiler plant—blast-furnace-gas fired boilers with pulverized fuel as standby—some improvements are required.

As has already been emphasized in the discussion, blast-furnace gas should not be regarded by boilermakers as a cheap fuel. Efficiency is as important as with coal.

The authors mention that the main problem in connection with steelworks boilers results from the unsteady demand for steam. The variable supply of the main fuel, blast-furnace gas, adds to this even where a gas-holder is employed.

The authors state that a large combustion chamber is necessary for blast-furnace gas. This could be reduced if burners gave better mixing of gas and air, and if more attention were given to proportioning air and gas between two or more burners. Deficiency of air on one burner and excess on another produces long-flame conditions. Owing to the constant variations to be countered, the boiler attendant is unable to correct these defects by trimming.

The turn-down range of gas burners is insufficient. It is necessary to have a very high degree of flexibility in a dual-fuel boiler so that the fuels can be fired at the same time in almost any proportion. The cast-iron flares of some large blast-furnace-gas burners burned through in the centre on low load so that the bottom half dropped off. Although a gas shut-off valve will be provided, the boiler attendant will not have time to shut off a burner by means of it unless it is in a convenient place. Pneumatic, or some similar means of operation would be useful in such cases. Linked gas and air butterfly-valves do not usually shut off tightly and result in gas or air passing through a closed burner and spoiling the gas/air ratio on another. Burners should not require cooling air.

Pulverized fuel is an admirable standby and unit pulverizers can take up the load very quickly. Trouble need not, I think, be expected with air heaters. As with gas burners, however, a wide degree of flexibility is required. Unit pulverizers get down to only half load comfortably and this is not sufficient. An improvement in this respect would result if greater consistency of grinding could be obtained. It is all too easy to increase load by coarsening the grinding, and heavy deposits in the combustion chamber result from this. Could not a constant rate of air recirculation through mill and classifier be provided so that the classifier worked under constant conditions ? The boiler attendant is required to give most of his attention to meeting the varying steam demand with all the gas that is available.

Turning to air heaters, I think the size of the

air heater is usually fixed so as not to get too low a waste-gas temperature under pulverized-fuel conditions. It is then too small for efficient use of blast-furnace gas. The recirculation system described by Dr. Bock, in combination with a larger heater, should go a long way to solve the difficulty of obtaining the same efficiency on both fuels.

With regard to water conditions, steelworks should not be tied to boilers suitable only for condensate feed like power-station boilers. It should be possible to use treated feed water and I think boilers could be designed to do so. Our 200-lb. pressure boilers give better steam conductivity figures with 250 grains of dissolved solids /gal. in the boiler water than our 400-lb. boiler which carried only 50 grains/gal.

So far as higher-pressure boilers are concerned I do not consider the extra cost of boiler-water conditioning likely to be serious. Even in the case of low-pressure waste-heat boilers, properly treated feed water pays in my experience.

I am glad that reference to the slip-ring motor has been made in the discussion ; it is as efficient as and cheaper than most of the alternatives mentioned, but I have not found it very suitable for automatic control of the speed ; it seems to respond very slowly. I think, however, that the D.C. motor is admirable from every point of view, and most works have direct current. I am not sure whether some of the means mentioned—the magnetic coupling for instance—are very convenient for the automatic control of speed.

I should like more information about soot blowers as after 4½ years we have worn holes in our superheaters on the 400-lb./sq. in. boiler.

Mr. **Peacock**: I appreciate very much the comments which have been made, because they are exactly what we wanted. Mr. Turner in particular seems to have touched on the very points which I was hoping that somebody would raise. The first was, why the difference between the water-tube boiler and the shell type ? The answer is that in the first place there is a tendency to use higher pressures, and the shell-type boiler is limited from a purely practical engineering point of view to going much above about 250 lb./sq. in. In the steel industry it is necessary to be able to burn satisfactorily a wide range of different fuels, and the shell-type boiler, with its compact little combustion chamber, is not very suitable for switching from solid fuel to a gaseous fuel. Therefore limitations are imposed on the type of boiler which are entirely divorced from any serious criticism of the boiler as a steaming unit. It is on the score of pressure and on account of the total evaporation required for the works, the undesirability of having a whole row of boilers, plus the fuel limitations imposed on the shell boiler, which have swung makers and users to water-tube boilers.

On the question of waste heat, when we say there is no problem for the designer we mean that there is no design difficulty in getting heat exchange, the inert gas being used for waste-heat conversion. Compared with the problems with which we were faced on water-tube boilers, we want to make the point that we are not discussing seriously today the tubular type of boiler which deals with inert gases, or the thermal exchange in the fire-tube type of boiler which has not produced any major difficulties. Where there are in practice occasional troubles in keeping the smoke-tubes clean, I feel that they are somewhat modest compared with the major problems which we are facing on the utilization of all your fuels in big boilers.

With regard to creosote–pitch and oil, the major point is that the viscosity is so different that for creosote–pitch tracer lines are required on the fuel-supply lines in order to avoid trouble with pumping and in order to avoid, after being switched off for some time, having the material about as solid as road tar so that it is difficult to start up again. The main difference, therefore, is that a creosote–pitch-fired installation would be equipped with tracer lines, with only a very slight difference in the burner tip to enable it to deal with the rather coarser material. You cannot switch straight from an oil-fired installation to creosote–pitch without a little bother.

I should like to communicate in greater detail individually with the speakers who have raised the question of blast-furnace gas. There has not been much trouble with it in this country, but, based upon reports from the U.S.A., where there have been some complaints, it has come to our knowledge that the bonded deposits which form on the boiler tubes as a result of the gas being damp are very much more difficult to remove even with soot blowers than anything which we have in this country today with the dirtier gases. We are not advocating dirty gas, and we should like to have clean gas ; but if we are going to have, as has happened in the U.S.A., the type of clean wet gas which gives rise to bonded deposits and lowers the efficiency of the boiler as a heat-transmitting unit and gives a good deal of trouble with regard to soot blowing, then on balance we would rather have the friable, easily-removed dust than the thin bonded deposits which we cannot get rid of. That is the point of our comment. There are not very much data available in this country on the subject.

I was asked whether I would prefer blast-furnace gas to be in continuous operation even when the quantity is low. On balance I would

say " Yes "; if it is there to be used, let us have it on the boiler, even if it is only 10% of the load, so as to keep the burners in commission, with air going through to keep them reasonably cool. There is a danger of burning the burners which are cut off from both gas and air. Even when the gas is cut off, it is still desirable to let a certain amount of air go through the burners, even with the loss of CO_2, to protect the burners from the heat of the other fuel. If, therefore, you have the blast-furnace gas, use it in the boiler.

On the question of CO_2 I agree with Mr. Turner ; if you know what it should be at a certain load, you can work on a CO_2 meter. The difficulty arises from the mentality of the average boiler operator and with automatic control. To try to make automatic control based on CO_2 decide from time to time whether the optimum CO_2 should be 13% or 20% or any range between the two, depending on whether you have 10% or 20% or 80% of blast-furnace gas mixed up with your pulverized fuel, is a task which makes my imagination boggle ; I should not like to put a master controller on to automatic combustion control based on CO_2. I was thinking in terms of an oxygen indicator so that you could tell the operator " Keep the oxygen meter round about here, and you will not be far wrong on the combustion side of the boiler plant," leaving the air/gas ratio to be unified on an air/gas ratio controller, and whatever the volumes they will vary in the correct proportion. It is my belief that the regulation of the combustion conditions on the solid fuel can best be done by visual observation of the furnace by the operator, helped by the oxygen control on an indicator. Have a recorder if you like, but I prefer it visible in the boiler house. Tell the operator to look at the fire and to see that he likes the look of it, and tell him to keep the oxygen controller at a point established by the ratio of blast-furnace gas to the remaining fuels.

I agree with what has been said about dust collection. We do not want dust about the place. We know that the Central Electricity Board are investigating dust problems. A dust burden leaving the chimney of 0·4 grains/cu. ft. seems to be the concentration which will be established, which means big precipitators on pulverized-fuel plants, and they are being installed. The manufacturers of mechanical dust collectors are getting recognized and are obtaining quite high efficiencies. Those of you who were at the Pulverized Fuel Conference last week at Harrogate will recollect the arguments there. We are finishing up in the doubtful position of having both belt and braces on some central power stations. It is likely that the space requirements for boilers will no longer be determined by the boiler size, but by the size of the precipitators, and in due course we shall obtain dust-burden figures which will satisfy the authorities. This is not a question for the boilermaker to settle.

If, in the steel industry, however, it so happens that it will be only for about 400 hr. a year that the boiler will be on full load with pulverized fuel, and for only 1000 or 2000 hr. it will be on half load with pulverized fuel, and variable supplies of coke-oven and blast-furnace gas are available, can you agree to spend a good deal of money on precipitators to get results which, much though we desire them, cannot be justified on a capital-cost basis ? If you can afford it, by all means have them ; but they are going to be a white elephant during those many hours when you are steaming on gaseous fuels or oil fuel. We are of course most anxious to have a clear stack.

I was asked whether there has been trouble with valve spindles. There has been trouble with valve spindles from time to time, but it has been very remote, and has probably been caused by using the wrong type of valve in a particular place, so that instead of using the correct alloy-steel spindle use has been made of an ordinary valve spindle designed for much less onerous conditions. When that has happened and the steaming conditions have been difficult, possibly with steam with carry-over, there may have been trouble from corrosion ; but the modern materials for valve spindles enable valves operating at very high pressures and temperatures to function without trouble.

The by-pass against gas explosion is rather difficult. I should like to be able to do it, but I suggest that the solution there lies in the intimate knowledge of the furnace designer of the composite burners which are installed. When the blast-furnace gas goes off, then on the assumption that you are not burning only blast-furnace gas the fires do not go out ; the evaporation does not stop ; one or other of the fuels is alight. If the proximity of one burner to the next is such that ignition takes place as soon as the lost fuel comes back, we should and do safeguard the boiler against this type of explosion. Explosion doors are put on a boiler to provide for these small puffs, but it is going to be very difficult, technically and practically, to introduce gadgets of the kind the questioner suggests, and which will work in practice.

I must endorse the President's remarks about low-grade heat. Outside the sphere of the steel industry very substantial steps are being taken ; the matter is well past the theoretical stage, and district heating can be and will be introduced in certain parts of the country. There is no reason why, if within the confines of your own steelworks

you have any other property that you want to heat, or any shops where winter heating is desirable, you should not pass low-grade heat to calorifiers, but do not take the good steam and let consumers use it without recovery of condensate.

Mr. Webber referred to fan control, and I agree with almost everything he said on that subject. As a boilermaker, of course, it would not become me to have likes and dislikes as to types of fan drive. There are a number of drives, and they are all available. So far as the D.C. motor is concerned, Mr. Robinson will agree that delivery may be difficult, and, of course, prices do vary. It means that we have to get together to decide on the merits of any particular set-up for the problem under review.

I agree very strongly with Mr. Lake on the question of distributing blast-furnace gas and air ; that is a very important point. We control adequately the air/gas ratio through the main. Then it comes into a bus main, and it goes where it will, and it does not always go to the right burner and there is not always the best combustion, and in some cases a lot of air goes through where it should not go. This matter is exercising our minds at the moment. We are trying to find out how best to deal with it without loading up the job with too many trimmings ; there should not be so many relays that they become a nightmare to the operator. I would myself prefer to have air going through a burner which is out of commission.

On the grinding of pulverized fuel, I can say that we do get a consistent grinding at a varying rate of load on most of the mills available today, but I would point out that what happens with regard to the changing of sizing and the carrying-over of the larger grading is that the coal changes. It is a very difficult problem, and we have got it down to a question of grindability tests. Some coals are twice as hard to grind as others, and to get the same output from the same mill means that you have a coarser sizing, because a reduction of output may not suit your boiler load. These problems have become intensified in the last year or two, insofar as those who are quite near a coalfield may have coal which has come from the other end of the country. Most of these troubles have been due to the change of coal, not to the shortcomings of the mill.

Why do we need good water ? I must put in a plea for the boilermaker here. We like good water. When pressures were low, we had trouble-free service from the older boilers. Transmission rates were low, and the scale on the inside of the tube did not do much harm. When I was in China, I had as a paperweight a piece of 4-in. tube built up with scale leaving only a 1-in. hole through it. This tube had been steaming for 20 years, and the outside surface was not even burnt, but it had only steamed at about 2 lb./sq. ft. evaporation, and the Chinese user did not realize that this was very low. If you wish to get the best out of a boiler, if you want to have (which is most important) security for your personnel, and if you are going to work at, say, the 600-lb./sq. in. pressure, it is not wise to take risks and to say that you can let your concentration build up, to throw in continuous blowdown, and continuously blowdown 20%. That will let a great deal of heat go to waste. Some can be recovered, but a good deal will be lost, and a good proportion of the solids in suspension will remain in the boiler. Particularly with water-cooled furnaces, with transmission rates of a very high order and radiant heat in the furnace, it is no use finding at regular intervals of six weeks or so that tubes burst and that the boiler is lost for a week.

We are impressed by practical considerations, and by the real necessity to give you long, trouble-free service, thinking in terms of the boiler giving a better availability even than a power-station boiler, because with the combination of pulverized fuel and blast-furnace gas I should be more inclined to be confident about long-term availability than I would on an ordinary power-station unit. In spite of the bother (much exaggerated sometimes) of water-treatment plant, I plead with all steelworks engineers to give it its right place in the jigsaw of the cycle and to have it investigated at an early date.

Mr. **Robinson** : Mr. Bridge suggested that I might have shown the optimum pressures for plant below 20,000 kW. He did say "if there was time," and that is the difficulty. I have done such work on other sizes of plant, but it takes a great deal of time and it means making many assumptions. If they were all set out, people would not agree with the results, and if I did not set them out the figures would not be worth much.

He also referred to cleaning condensers. The method in question has been used in central power stations, and the reason why it is not used more is that with the interconnection of the grid there is no need to use it ; it is possible to lay the plant off at suitable times.

He suggested that the generator turbines should come before the blower turbines in the steam cycle. It is matters of that kind which could be settled by discussion between the two sides.

The President raised the question of standards. The B.S.I. have adopted those standard symbols. They were first raised by the I.E.C. at Stockholm in 1933 and adopted internationally, and shortly after that the B.S.I. adopted them for this country.

I am afraid that I am on the other side of the fence when Dr. Desch talks about centigrade and Farenheit. I am one of those on B.S.I. Committees who have objected very strongly to centigrade. I have to do the calculation to which Dr. Desch referred in the reverse direction.

District heating is well advanced and several schemes will come into operation.

Written Contributions

Mr. **G. D. Toogood** (The Superheater Co., Ltd.) : There have been comments made during the discussion by several of the speakers in connection with the severely fluctuating loads imposed by steelworks on power plant. These comments, together with the remark made by one of the contributors to the discussion concerning the desirability on the part of ironworks engineers for feed-water to boilers being other than that of the very pure quality called for in power-station practice, invites a comment from superheater manufacturers.

Provided that the oxygen content of boiler water is kept very low and provided that, either by chemical dosing internally to the boiler or by feed-line dosing, the salts in the boiler water are brought down as a sludge and not as a hard scale, then there would appear to be only one factor which operates against boiler-water concentrations reaching the high figures which bad water would necessarily bring about. This factor is the efficient, or otherwise, design of the boiler internal baffling which is situated between the saturated side of the boiler and the superheater.

There is a relationship between the boiler-water concentration, the efficiency of the baffling, the load, and the amount of carry-over into the superheater for any boiler. The carry-over from the saturated side of the boiler will reach one of two places, in either of which it is liable to produce serious effects upon the efficient running of the plant. The salts associated with the droplets of saturated steam which leave the saturated drum will be deposited as a result of evaporation either in the superheater or on the turbine blading—or they may even circulate right back to the boiler in a closed system.

One can say therefore that if it is desired to operate a boiler for an iron and steel works plant or for any other plant with severely fluctuating load requirements with a boiler water of high concentration, then particular care must be paid to the obtaining of saturated steam of high purity, and clauses to obtain this result are often included in boiler specifications. This calls for detailed consideration during the design stages of the boiler internal baffling and to the circulation of the boiler water and during the operating life of the boiler to the maintenance in good condition of the baffles which have been fitted.

Heat wastage, consequent upon the use of excessive blowing down called for if the boiler-water concentration is to be kept at a reasonable figure and if the feed-water is not of a particularly pure quality, can be avoided by introducing the heat in the blow-down back into the feed system through a heat exchanger.

Mr. **A. Ridings** (Messrs. Daniel Adamson and Co., Ltd.) : The absolute necessity of securing the highest overall thermal efficiency of a steelworks is a prime consideration of the management, especially in these days of high fuel costs. The last ditch in the fight to attain the best results is in the power house and its associated boiler plant.

Whether the works are a fully integrated unit or undertake a limited number of processes, the steam-raising units usually carry the burden of meeting demands—steady or variable—with a basic fuel supply which may fluctuate to a considerable degree, quickly, and without notice.

The works' cycle, *e.g.*, blast-furnaces–boilers–blowers–blast-furnaces, is also tight, so that a furnace " going sick " has an immediate effect all round, yet the demand for blast may vary quite out of step with the other factors.

It is generally found that the load factor in a steelworks is appreciably higher than in industry in general and relatively on a par with base-load power stations, this especially being so in the case of a seven-day week.

For these reasons one arrives at the following general conclusions :

(1) High thermal efficiency requiring the use of medium–high pressures and temperatures with a measure of feed heating is economically justified.

(2) There must be available an alternative supply which can be put into use quickly.

The exact details of the steam cycle naturally depend on the power production entailed, but for an average steelworks the writer agrees with Mr. Robinson that 400 lb./sq. in. (gauge) and 750° F. at the turbine stop valve is at least likely to prove a useful first basis for consideration.

The use of blast-furnace gas makes it almost imperative to use preheated air both to effect the last stage of heat transfer and to assist greatly in the efficient burning of the fuel.

If coke-oven gas is also available it is advantageous to use separate burners as this leads to much easier control and more efficient combustion. At the same time this fuel makes it very necessary to consider the metal temperatures at the cold end as determined by feed and air-inlet temperatures, otherwise, with the high wet-gas content, corrosion will occur.

With blast-furnace gas as the only gaseous fuel, fuels which can be brought into use most quickly, handled most efficiently and easily, and requiring a combustion chamber of similar shape, dimensions, and construction, are pulverized coal or pitch, oil fuel, or liquid pitch.

The use of coke breeze as the secondary fuel can be justified only on the rarest occasions. This fuel is not likely to be the drug on the fuel market, as was the case up to quite recent times.

It is right to stress the paramount need to maintain the highest combustion-heat efficiency and the influence of automatic control in securing it.

Space is likely to preclude all except cursory mention of such matters as balancing the number and capacity of the fans to give efficient operation when meeting widely differing conditions and a measure of standby capacity ; the disposition of the heating surfaces to ensure not only efficient transfer, but also cleanliness and hence long periods of availability at high efficiency, and the possibility of generating at high efficiency process steam for the producers, mills, etc., by secondary steam generation on a closed circuit parallel with the main steam cycle.

Mr. **H. N. Simpson** (Messrs. Cochran and Co., Annan, Ltd.) : I note that at the beginning of the third paragraph under the sub-title " Automatic Control " it is stated " Where one of the fuels is blast-furnace gas or coke-oven gas, the measurement of CO_2 is not an accurate indication of the combustion conditions, but instruments are available for recording the oxygen in the flue gas, which is a better guide (*see* Fig. 1)."

Now, for the fuels shown on the diagram on page 95, there is a wide variation in the curves for CO_2 and percentages of excess air, but very little variation in the curves for O_2 and percentages of excess air, so the above statement can be taken as correct for mixtures of the fuels shown. Curves for blast-furnace gas, however, are not shown and I submit that if they had been it would have been noticed that the oxygen curve differed considerably from those on the diagram.

For example, the composition of a typical blast-furnace gas might be as follows :

Carbon dioxide	11%
Carbon monoxide	27%
Hydrogen	2%
Nitrogen	60%
	100%

The theoretical quantity of air required for combustion of this gas is 0·69 cu. ft./cu. ft. of gas and the theoretical quantity of dry products of combustion is 1·53 cu. ft., giving a CO_2 content of 24·9%. Percentages of CO_2 and O_2 for different percentages of excess air are as follows :

Excess air, % ...	0	10	20	30	40	50	60
CO_2, % ...	24·9	23·8	22·7	21·9	21·1	20·3	19·5
O_2, %	0	0·9	1·7	2·5	3·2	3·9	4·5

These values for oxygen when plotted on the diagram give a curve which is sufficiently different from the other oxygen curves to indicate that when one of the fuels is blast-furnace gas the measurement of oxygen in the products of combustion is also an inaccurate indication of the combustion conditions.

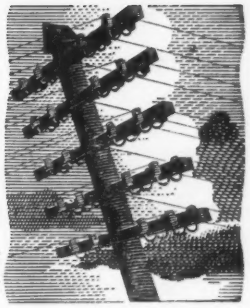
Replies to Written Contribvtions

Mr. **Peacock** (in reply to the written contributions) wrote : Mr. Toogood points out that the superheater should be free from carry-over, and I heartily agree with him in this direction. The boiler-makers have made great headway with dry pipes, cyclones, and steam scrubbers, which keep the carry-over at a minimum. I cannot agree with him that chemical dosing only would permit high concentrations to be carried in the boiler. Surely the pressure at which the boiler operates together with the furnace transmission rates are of the greatest significance. I would say that even after chemical treatment and de-aeration the concentration would be a function of pressure, and continuous blowdown would then be required to retain the concentration below the established figure. It may be that the thermal cycle would restrict the percentage of continuous blowdown.

With regard to Mr. Riding's remarks I would differ only on the question of having separate burners for blast-furnace and coke-oven gas. I would prefer combination burners, both from the operating point of view and maintenance, and also the practical considerations governing the furnace design and construction.

Mr. Simpson points out that the oxygen measurement is inaccurate in connection with combustion, and I agree with him. The comment in the paper stressed the substantial inaccuracy of CO_2 and stated " but instruments are available for recording the oxygen in the flue gas, which is a better guide." It is agreed that the oxygen content in flue gas from blast-furnace gas varies from the oxygen content from other fuels, but if the CO_2 for blast-furnace gas is plotted against that of other fuels, it will be seen that the variation is of a much more substantial nature, and therefore I suggest that oxygen measurement is better than CO_2, although it cannot be argued that oxygen will be constant if blast-furnace gas is one fuel of a mixture and the percentage fluctuates.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

IRON AND STEEL INSTITUTE

Life Membership for Members of 50 Years' Standing

The Council of the Iron and Steel Institute has decided that Members of fifty years' standing shall in future become Life Members without further payment. This ruling will take effect from 1st January, 1948, in the case of those who have already been Members for over 50 years, and in the case of others, from the beginning of the year following that in which their fifty years of Membership is completed. Eleven Members will have completed fifty years' Membership by the end of this year, in addition to five who hold honorary positions.

Life Members have the same privileges as other ordinary Members.

Jernkontoret

The Council of the Iron and Steel Institute has decided to award a special Bessemer Gold Medal to Dr. h.c. Magnus Tigerschiöld, Director of Research of Jernkontoret, in recognition of his distinguished services to the iron and steel industries of Sweden and as part of their tribute to Jernkontoret on the occasion of the celebration of the two hundredth anniversary of the foundation of the Association.

The Medal will be presented by the President during the anniversary celebration in Stockholm, on 5th and 6th September, 1947.

The Institute will also present to Jernkontoret a complete set of volumes of the *Journal*, from 1869 to 1945, with the Carnegie Scholarship Memoirs and Special Reports, specially bound for the purpose.

The President, Dr. C. H. Desch, F.R.S., Mr. Arthur Dorman, Past President, and the Secretary, Mr. K. Headlam-Morley, have accepted invitations to represent the Institute. The British Iron and Steel Federation will be represented by Sir John Duncanson, Commercial and Technical Director, and the British Iron and Steel Research Association by the Director, Sir Charles Goodeve, F.R.S., O.B.E.

Andrew Carnegie Research Fund

The Council has made the following award:

A **Research Grant** of £200 to Monsieur Robert Guenot for an investigation on "Electrical Properties of Cold-Worked Metals and Alloys," to be carried out at the University of Sheffield.

ASSOCIATION OF ENGINEERS, LIÈGE

The International Exhibition of Scientific Research and Industrial Control, to be held in connection with the centenary of the foundation of the Association des Ingenieurs sortis de l'Ecole de Liège, will be officially opened on 9th August, 1947, by Mr. P. H. Spaak, Prime Minister, and Members of the Government. The celebrations include a Congress. to be held from 30th August to 14th September, at which the Institute will be represented.

The Exhibition is being held in the University Institutes of Val-Benoît and lasts until 28th September. It has been organized with the object of showing to technicians, engineers and manufacturers how the methods of scientific research and industrial control help to improve the quality of materials, manufacturing processes and the value of the finished products.

Nearly 200 foreign firms will be showing exhibits in addition to the exhibits of the University Institutes, and the stands will cover more than 12,000 sq. m.

The comprehensive programme covers guided visits to the Exhibition at the weekends of 9th, 16th and 23rd August; the opening of the Congress on 30th August, for discussions of geological, metallurgical and chemical problems as well as other problems affecting industrial control, and many social activities and excursions during evenings and free periods.

Staff Biography No. 8

Mr. C. ROWLAND HARMAN, Assistant Editor, was born in 1912, at Ightham, Kent. Educated at Ashford Grammar School, he carried on further studies at the Polytechnic, London, and obtained the degree of B.Sc. (Eng.), of London University in 1932.

In 1930 Mr. Harman joined the London offices of Messrs. Dorman, Long & Co., Ltd., where he gained a general experience of the design and construction of large steel-framed buildings and bridgework. He left, in 1934, to take up a position as draughtsman and designer at the Constructional Works of Messrs. John Lysaght, Ltd., Bristol, and in 1937 he was given charge of the development of welding in the firm's products.

Through his contacts with Professor J. F. Baker, then at Bristol University, Mr. Harman became interested in the work of the Welding Research Council of the Institute of Welding, and he left Bristol, in 1939, to become a research assistant (structural) at the Institute. He was appointed deputy director during the period when the Director of Research, was setting up the Advisory Welding Service, Ministry of Supply.

From 1941 to 1943, Mr. Harman was seconded to the Department of Tank Design, Ministry of Supply, and was appointed as officer-in-charge to develop and maintain a research section to investigate the welding of armour plate and the development of austenitic electrodes. He obtained his release from the Ministry of Supply in 1943, on being invited to become Secretary of the Admiralty Ship Welding Sub-Committee, and was responsible for the administration of research including large-scale testing of ships' structures, and the brittle fracture of mild steel.

With the re-organization of the Welding Research Council and the setting up of the British Welding Research Association in 1945, Mr. Harman resigned his appointment as Secretary to undertake the development of a Library and Information Department for the Association and also the publication of research reports. He joined the staff of the Institute in November, 1946. Mr. Harman has read a number of papers on the welding of steel structures to members of the Institute of Welding and the Institution of Structural Engineers.

NEWS OF MEMBERS

▸ Mr. J. H. ASTON has retired from the board of Tube Investments, Ltd.

▸ Mr. G. T. HARRIS has been appointed Research Manager to Messrs. William Jessop & Sons, Ltd., and Messrs. J. J. Saville & Co., Ltd., Sheffield, under the present Director of Research, Mr. D. A. Oliver.

▸ Mr. B. KRISHNAMURTHY will be working for a few months at the South Works of the Carnegie Illinois Steel Corporation, Chicago, U.S.A., before he proceeds to England.

▸ Lt.-Col. M. A. WOLFF has resigned from the board of Tube Investments, Ltd., but is retaining his appointments with subsidiary companies of the group.

▸ Dr. R. V. RILEY has been appointed Research Manager, Foundries, at the Staveley/Bradley and Foster Research Department of the Staveley Coal and Iron Co., Ltd., Chesterfield.

▸ Mr. G. M. MENZIES has been appointed a Director of the General Accident Fire and Life Assurance Company.

▸ Mr. H. HENDERSON has been elected Chairman of the Foamed Slag Producers Federation.

▸ Mr. E. A. REYNOLDS has relinquished his appointment as an Assistant Managing Director of Tube Investments, Ltd., but retains his seat on the board.

▸ Mr. J. F. WHITFIELD has been appointed Chief Engineer of Birmetals, Ltd., Birmingham.

▸ Mr. SONATON NANDI, of Calcutta, India, is setting up a new Foundry under his own ownership.

▸ Mr. I. M. MCLENNAN has been appointed Assistant General Manager of the Broken Hill Proprietary Co., Ltd., Australia.

▸ Eng. Vice-Admiral Sir HAROLD BROWN, G.B.E., K.C.B., has been appointed Chairman of the Machine Tool Advisory Council, by the Ministry of Supply.

▸ Mr. E. J. PRINCE has joined the Dominion Steel and Coal Corporation, Ltd., Sydney, Nova Scotia.

▸ Mr. J. N. KILBY has joined the Board of the Blaenavon Company.

▸ Mr. A. POOLE has resigned from his position as Chief Engineer of Messrs. Davy and United Engineering Company, Ltd., and has been appointed whole-time consulting engineer.

▸ Mr. W. W. FRANKLIN has been promoted Chief Engineer of Messrs. Davy and United Engineering Co., Ltd., Sheffield.

▸ Mr. W. CRAIG has been appointed Assistant Chief Engineer in charge of sectional-rolling mill design at Messrs. Davy and United Engineering Co. Ltd.

▸ Mr. C. H. DAVY has been appointed a Director of Messrs. Babcock and Wilcox, Ltd.

▸ Mr. E. H. ARMITAGE has resigned his chairmanship of the Hoffman Manufacturing Company, but retains his seat on the Board.

▸ Mr. L. COOK has left England to take a position with Companhia Siderúrgica Nacional, Volta Redonda, Brazil.

▸ Dr. H. O'NEILL will take up his appointment as Professor of Metallurgy, Swansea University, from 1st September, 1947.

▸ Mr. W. R. ELLIOT has been promoted to General Superintendent, Otis Works, of the Jones and Laughlin Steel Corporation.

Elections

▸ Mr. N. SEN, Chief Chemist of the Tata Iron and Steel Co., Ltd., Jamshedpur, India, has been elected President of the Section of Engineering and Metallurgy, for the 35th Session of the Indian Science Congress Association, to be held in January, 1948.

▸ Mr. F. B. FOLEY has been nominated for President of the American Society for Metals.

▸ Mr. F. E. STOCKELD has been elected President, and Mr. W. E. BALLARD, Vice-President, of the Birmingham Metallurgical Society for the session 1947–1948.

▸ Monsieur A. MEYER (Hon. Vice-President of the Institute) has been nominated President, and Monsieur F. Chomé, Directeur Général, of A.R.B.E.D.

Awards

The President and Members of Council offer their congratulations to the following Members:

▸ Mr. F. A. FOX, Assistant Director of the British Welding Research Association, who has received the degree of D.Sc. from the University of Birmingham.

▸ Mr. B. KRISHNAMURTHY, who has been awarded the degree of M.Sc.(Met.), by the University of Minnesota, U.S.A.

▸ Mr. P. BROCK, who has been awarded the degree of Bachelor of Metallurgy by the University of Sheffield.

▸ Mr. E. T. TÜRKDOĞAN, who has been awarded the degree of Bachelor of Metallurgy by the University of Sheffield.

▸ Mr. E. V. TULL, who has received the degree of B.Sc., with 2nd Class Honours in Metallurgy, at Leeds University. He is being conscripted into the Army.

▸ Mr. J. E. ROBERTS, who has graduated as B.Eng., with 1st Class Honours in Metallurgy, at Liverpool University, and is now joining the English Electric Co., Ltd., Stafford.

Obituary

The Council regret to record the death of:

Monsieur G. BARBANSON, President of A.R.B.E.D.

CONTRIBUTORS TO THE JOURNAL

M. Tchorabdji Simnad, Ph.D., A.R.S.M.—Research assistant in the Corrosion Section of the Metallurgy Department, University of Cambridge.

Dr. Simnad was born in Teheran, Iran, and received his early education in Istanbul and England, later entering the Imperial College of Science and Technology, London, where he obtained his B.Sc. degree and A.R.S.M. in 1941. He entered Cambridge University the following year with a British Council Research Scholarship, and was awarded a Ph.D. degree for his work on corrosion-fatigue and stress-corrosion of steel.

During vacations Dr. Simnad gained valuable experience in English and European coal and metal mines, factories and technical centres.

Since 1945 he has been carrying out research for the British Iron and Steel Research Association at the University of Cambridge, under the direction of Dr. U. R. Evans.

U. R. Evans, M.A., Sc.D.—Reader in the Science of Metallic Corrosion at the University Chemical Laboratory, Cambridge. Dr. Evans was

educated at Marlborough College and received further academic and technical education at King's College, Cambridge, where he obtained his B.A. degree in 1910 and a M.A. degree in 1914. He received the degree of Sc.D. in 1932.

Apart from numerous visits abroad to give lectures by invitation, and service in the Armed Forces during the First World War, Dr. Evans has devoted his time to research on metals at Cambridge University. His work has been applied particularly to corrosion reactions, a subject in which he is a recognized authority and on which he has written numerous books and papers.

Dr. Evans was elected a Member of the Iron and Steel Institute in 1924, and has also been a Vice-President of the Faraday Society and the Cambridge Philosophical Society.

A. E. Lance—Principal Control Officer (Ores and Refractories), Metallurgical Industries (Ferrous), Control Commission, Germany. Mr. Lance

was born in Cape Colony, in 1887, and was educated at the South African College School, Balliol College, Oxford, and the South African School of Mines and Technology.

Mr. Lance has had a very wide and varied experience of mines in many parts of the world—gold and coal mines in South and West Africa, nickel mines in Canada, copper mines in the United States, iron ore mines in France, and gold and coal mines in India.

During the Great War Mr. Lance was in France with the 185th Tunnelling Coy., R.E., and from 1940 to 1943 he was D.C.R.E., Northern Command, Great Britain. His present post with the Military Government is at Düsseldorf.

IRON AND STEEL ENGINEERS GROUP

Engineering Committee

The Group has now been in existence for one year and has a membership of approximately 1200.

The Council of the Institute felt that at the beginning of the second year of the Group's life, it would be advantageous to expand the Engineering Committee so as to make it more representative of the various engineering aspects of the iron and steel industry and of the different districts of the country in which iron and steel works are located.

The members of the original Committee were invited to continue in office for another year and a number of other engineers were invited to serve.

The following is the present membership of the Committee as from 13th May, 1947 :

Chairman

Mr. W. F. CARTWRIGHT	Guest, Keen, Baldwins Iron and Steel Co., Ltd.

Members

Mr. W. B. BAXTER	Appleby-Frodingham Steel Co., Ltd.
Major W. R. BROWN, D.S.O.	Ashmore, Benson, Pease & Co., Ltd.
Mr. J. BUCHANAN	Priest Furnaces, Ltd.
Mr. H. S. CARNEGIE	English Electric Co., Ltd.
Mr. M. A. FIENNES	Davy and United Engineering Co., Ltd.
Mr. D. C. HENDRY	Stewarts and Lloyds, Ltd.
Mr. J. F. R. JONES	John Summers & Sons, Ltd.
Mr. E. T. JUDGE	Dorman, Long & Co., Ltd.
Mr. H. H. Mardon	British Iron and Steel Research Association
Mr. G. A. PHIPPS	Guest, Keen and Nettlefolds, Ltd.
Mr. L. ROTHERA	Colvilles, Ltd.
Mr. I. S. SCOTT-MAXWELL	British Iron and Steel Federation

Ex Officio

Dr. C. H. DESCH, F.R.S.	President, The Iron and Steel Institute
Hon. R. G. LYTTELTON	Hon. Treasurer, The Iron and Steel Institute

It was agreed that starting from the Annual General Meeting in 1948, members of the Committee should retire in rotation. No fixed term of office has been laid down. It is the Council's policy to ensure that the Committee shall continue to be representative of the major engineering aspects in the industry and account will be taken of this when arrangements are made for members to retire.

Meetings

The Group held two meetings in 1946 and has, so far, held two meetings in 1947. The **Fifth Meeting** will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 26th November, 1947. The morning session will be devoted to the presentation and discussion of a paper on "*The Mechanical and Electrical Features of the Principal Hot Rolling Mill Auxiliaries*," by W. W. Franklin, Davy and United Engineering Co., Ltd., and P. F. Grove, John Miles and Partners (London), Ltd.; during the afternoon session a paper on "*The Development of Modern Small Rolling Mills*," by G. A. Phipps, Guest, Keen and Nettlefolds, Ltd., will be presented and discussed.

It is intended to hold three one-day meetings in London during 1948, one in February, one in early June, and one in October or November. The exact dates and the subjects to be discussed will be announced later.

It is also intended to arrange a number of meetings outside London during 1948, in conjunction with local societies affiliated to the Iron and Steel Institute. It is hoped by this method to afford an opportunity for discussing engineering problems to those iron and steel works engineers who are unable to attend London meetings.

Papers

It is one of the major duties of the Engineering Committee to advise the Council of the Institute on the contents of the "Iron and Steel Works Engineering" Section of the *Journal*. The Committee is also anxious that members of the Group and other engineers within, or connected with, the iron and steel industry, should submit papers on engineering subjects to the Institute, with a view to their publication in the "Iron and Steel Works Engineering" Section of the *Journal*.

It is the hope of the Committee that this Section of the *Journal* should be regarded as one of the

recognized channels for the discussion of iron and steel works engineering problems.

As stated on page 622 of the April issue of the *Journal*, it is a function of the Engineering Committee to make recommendations to the Council for awarding the Ablett Prize. The Committee will be prepared to receive papers on engineering subjects from younger engineers in the industry, with a view to their consideration for the award of the Ablett Prize and for their publication.

The Committee intends to arrange for the publication, in the Engineering Section of the *Journal*, of short technical descriptions of new items of plant. It is hoped that companies which bring new plant into operation will send suitable technical descriptions to the Institute.

The Committee also welcomes short notes or articles concerning practical ideas for the improvement of steel works equipment and processes, with a view to their publication in the Engineering Section of the *Journal*. Members and other engineers are therefore invited to submit any such short notes or articles as they may think would be of interest to other engineers.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

South Wales Laboratories

The South Wales Laboratories of the Association were opened at Sketty Hall, Swansea, by the President, Mr. G. H. Latham, on 3rd July, 1947. The opening ceremony was followed by an inspection of the laboratories and lunch at the Swansea Civic Centre. Short speeches were made by the Mayor, Mr. G. H. Latham, Mr. Percy Morris, M.P., Sir Lewis Jones (Vice-President of the University College of Swansea), Captain H. Leighton Davies (Chairman of BISRA Coatings Committee), and Sir Charles Goodeve. The speakers outlined the origins of the laboratories and welcomed the facilities they would provide for direct co-operation between the research teams of the Association, the University and the industry at large.

The Sketty Hall Laboratories form part of the scheme of the steel industry to establish, through the Association, a number of laboratories for the purpose of co-operative research. At Sheffield University a team is studying problems connected with rolling practice, and plans are well advanced for the establishment of a Metal Flow station in Sheffield, for practical investigations into all forms of metal working and plastic deformation problems; in London a physics laboratory is shortly to be opened; there is a corrosion-testing laboratory at Birmingham and a marine biological station at Millport, Scotland. The main function of these laboratories is to undertake investigations which lend themselves particularly to co-operative effort. In the main these lie somewhere between theoretical research carried out at universities and similar institutions and the practical or applied research which is carried out at the works of individual firms. At Swansea the majority of the work is concerned with metal surfaces and coatings on steel, though a limited amount of other work is also to be undertaken.

The organization of the Swansea laboratories is the task of the Coatings Committee of the Mechanical Working Division of the Association, one of the six divisions under which BISRA's work is organized. This committee was formed about 14 months ago, and the first meeting was held on the 15th May, 1946, under the chairmanship of Captain H. Leighton Davies, C.B.E., who remains the chairman today.

The greater portion of the work at Sketty Hall is to be carried out on behalf of the Coatings Committee, but work is also to be undertaken for the South Wales Steel Sub-Committee, also under Captain Leighton Davies' chairmanship, which is part of BISRA's Steel Making Division.

At the present time Mr. Luther Phillips, M.Sc., F.R.I.C., who is in charge of the laboratories, has a staff of nine full-time investigators who, together with research assistants, instrument mechanic, glass-blower, administrative staff and so on make up a total staff of about twenty. Senior officers so far appointed include Mr. L. Hughes, M.Sc., in charge of the Metallurgy Section; Dr. Pearson in charge of Chemistry; Mr. M. R. Hopkins, M.Sc., in charge of the Physics Section, and Mr. Roye, B.Sc., in charge of the work for the Steel Making Division.

The three floors of the new laboratories provide ample accommodation which includes chemistry, physics and metallurgical sections, an electrochemical section and metallographical laboratories as well as adequate administrative offices and a library. The setting up of the new laboratories has not seriously interfered with the work of the two research committees, which was formerly carried out at Swansea University College, and it is expected that reports of the work already completed will soon be published in the BISRA Section of the *Journal*.

New Committees

The Plant Engineering Division is setting up a new main research committee on Electrical Engineering, under the chairmanship of Mr. W. M. Larke. The new committee will be responsible for the existing Steelworks' Cranes Sub-Committee and the new Blast-Furnace Engineering Sub-Committee, referred to on page 432 of the July issue of the *Journal*.

The Mechanical Working Division is setting up

a new Sub-Committee of the Drawing Committee to be known as the Experimental Wire-Drawing Machine Sub-Committee. Mr. G. R. Bolsover is the Chairman. The Sub-Committee will be mainly concerned with research on back-pull drawing, but other problems, such as those affecting the design of dies, may also be included in the field of study.

Layout of Blast-Furnaces

The Plant Engineering and Iron Making Joint Conference on the Layout of Blast-Furnace Plant was held on 12th June, at Ashorne Hill, under the chairmanship of Mr. W. B. Baxter. Four papers were presented by members of firms about to erect new iron making plant, or to extend existing works. In addition to the discussion of new proposals, the shortcomings of existing plant were emphasized. The proposed scheme for the new works to be erected at Margam by the Steel Company of Wales was illustrated by a scale model showing how the new buildings will fit into the existing site.

Staff Appointments

Mr. RANKINE, who has been head of the Rolling Mill Research Team at Sheffield since December, 1945, is shortly resigning to take up a position with the Whitehead Iron and Steel Co., Ltd. He will remain at Sheffield for a short while, in an advisory capacity, before taking up his new post.

Mr. W. H. BAILEY has been made Head of the Rolling Mill Research Team. He is in charge of the rolling mill research programme at the laboratories of the University of Sheffield, in St. George's Square.

Mr. C. N. KINGTON is being made responsible for the establishment of the Metal Flow Station.

NEWS OF SCIENCE AND INDUSTRY

Fulmer Research Institute

The Fulmer Research Institute, Stoke Poges, Bucks, was opened on 2nd July, 1947, by Sir Stafford Cripps, President of the Board of Trade. Afterwards Col. W. C. Devereux, Founder and Chairman, and Mr. E. A. G. Liddiard, Director of Research, spoke of the establishment of the Institute and of its aims and the facilities provided for research.

The Institute has been founded, on the lines of American organizations such as the Battelle and Mellon Institutes, to provide a research centre with adequate facilities and experienced scientists which can be used by firms to carry out research work on their behalf.

The work of the Institute is at present mainly confined to the metallurgical field. It is open to consultation on everyday problems but its main research programme is concerned with the evolution of new processes and products or the improvement of existing ones.

Fabricated Carbon Products

Powell Duffryn Ltd., through its subsidiary company, Delanium Ltd., has for some time been engaged in research, experimental and development work in the production and fabrication of carbon products at laboratories at Battersea. A new subsidiary company, Powell Duffryn Carbon Products Ltd., has now been formed to undertake the commercial production of such carbon products at Hayes, Middlesex, and the name Delanium and associated trade marks are being taken over by the new Company.

Increased Railway Wheel Production

The modernization of the plant at Messrs. Steel, Peech and Tozer, Ltd., Sheffield, commenced in 1944 with the installation of a new cogging mill, which is now dealing with a weekly input of about 15,000 tons. A further step in reconstruction is the proposed reorganization of the wheel mill, which is designed to increase the firm's output of railway material by 30%. A new mill building and a new warehouse are to be constructed and almost all of the existing machinery is to be replaced. New equipment includes a 6,000-ton forging press, a vertical type wheel-rolling mill, re-heating furnaces and heat-treatment plant. Hydro-electric power will be used in place of the present steam power and all furnaces will be fed by coke-oven gas.

The firm's steel production is also being increased by improvements in charging and handling equipment and by the conversion of some furnaces to oil firing. When the full modifications have been completed a total annual output of nearly 800,000 tons is expected.

New Continuous Rod Mill

The output capacity of the continuous rod mill at Messrs. Richard Johnson and Nephew's Bradford Ironworks, is to be approximately doubled by the installation of a new, 19-stand, straight-through, two-strand continuous mill. The semi-finishing and finishing stands (Nos. 9 to 18) are already installed and are partially in operation, receiving one strand from the present finishing train. Output is maintained at present by the use of one of the old finishing trains until the new installation is complete. The new coilers and hook conveyor are installed and in use, as well as a new gas machine for the re-heating furnace. When it can be done with the least interference with production, the present roughing mill will be taken out, and the new roughing

mill (stands 0 to 6) and intermediate mill (stands 7 and 8) will be installed, while at the same time certain alterations will be made to the furnace arrangements.

It is hoped that the new installations will be completed by the autumn of this year. After this a considerable reorganization of the wire mill, and a 30% increase of galvanizing capacity is contemplated.

AFFILIATED LOCAL SOCIETIES

Leeds Metallurgicial Society

The new list of Officers for the session 1947—1948 is as follows :

President

A. PREECE

Past-President

Major KITSON

Vice-Presidents

W. R. BERRY — J. ARTHUR SYKES

Hon. Treasurer — D. E. CATTON

Hon. Secretary — W. J. G. COSGRAVE

Members of Committee

R. E. CAMPBELL — H. F. POOLE
K. J. IRVINE — H. D. WARD
F. LINDARS — J. WILKINSON

The following programme has been arranged for the new Session :

1947

2nd Oct.—"*Industrial Copper Alloys*," by Dr. Maurice Cook.
6th Nov.—"*Magnesium Alloys*," by Dr. F. A. Fox.
3rd Dec.—"*Aluminium Alloys*," by Mr. H. G. Warrington.
4th Dec.—Dinner Dance.

1948

8th Jan.—Symposium on Casting.
5th Feb.—"*Investigation of Failures*," by Mr. C. P. Miller.
4th Mar.—Discussion of Iron and Steel Institute Papers. Joint meeting with local Members of the Institute.
— Mar.—Social Evening.
1st Apr.—"*Controlled Atmospheres*," by Mr. Ivor Jenkins.
6th May—Annual General Meeting and Student Members' papers.

Swansea and District Metallurgical Society

The Annual General Meeting of the Society was held in Swansea, on 2nd July, 1947. The following Officers and Members of Council were elected for the 1947—1948 Session :

President

E. A. DAVIES

Vice-Presidents

T. J. CANNING — M. L. HUGHES, M.Sc.

Hon. Secretaries

L. PERRETT — H. A. COOKE

Members of Council

D. L. BLEWITT — R. W. EVANS, M.Met.
H. N. BOWEN — R. GRIFFITHS, M.Sc.
Capt. H. L. DAVIES (representing the Iron and Steel Institute) — D. G. NEWMAN
W. J. SHIPTON
R. WALKER
G. DAVIES

INSTITUTE OF METALS

39th Annual Autumn Meeting, 1947

The 1947 Autumn Meeting of the Institute will be held in Glasgow, from 23rd to 26th September, by the invitation of the Scottish Local Section.

The Programme opens with a reception on the evening of Tuesday, 23rd September, by Sir James Weir French and other distinguished members of the reception committee. This will be followed by the presentation of the Twenty-Fifth Autumn Lecture by Professor G. Wesley Austin (Vice-President), who will speak on "*The Metallurgical Resources of Scotland.*"

During the next two days, Wednesday, 24th, and Thursday, 25th, the following papers will be presented for discussion at the meetings, which will be held at the Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow :

Wednesday, 24th Sept.

"*Surface Effects during the Annealing of 70/30 Brass*," by Ivor Jenkins.
"*The Centrifugal Casting of Copper Alloy Wheels in Sand Moulds*," by O. R. J. Lee and L. Northcott.

Thursday, 25th Sept.

"*Frictional Properties of Some Lubricated Bearing Metals*," by P. G. Forrester.
"*Corrosion of Magnesium Alloys*," joint discussion of three papers.
"*Metallographic Study of the Precipitation of Copper from a Silver-Rich Copper–Silver Alloy*," by M. L. V. Gayler and W. E. Carrington.

In addition to the discussion of papers, arrangements have been made for a Civic Reception at the City Chambers, visits to local works and excursions, and social functions for the evenings.

Full particulars of the meeting may be had on application to the Secretary at 4, Grosvenor Gardens, London, S.W.1.

DIARY

2, Aug.–28, Sept.
ASSOCIATION OF ENGINEERS, LIÈGE — International Exhibition of Scientific Research and Industrial Control.

1–12, Sept.
UNIVERSITY OF CAMBRIDGE—Summer School in Metal Physics, Cavendish Laboratory.

5–7, Sept.
INSTITUTION OF METALLURGISTS — Refresher Course, *Transformations in Solid Metals*, L.M.S. School of Transport, Derby.

8, Sept.
INSTITUTION OF METALLURGISTS—Examinations for Licentiateship, commencing in London and other centres.

12, Sept.
Engineering and Marine Exhibition. Official visit of Council and Officers of the Iron and Steel Institute.

17–18, Sept.
ELECTRODEPOSITORS' TECHNICAL SOCIETY — Third International Conference on Electrodeposition, Hyde Park Hotel, London.

23–26, Sept.
INSTITUTE OF METALS—Autumn Meeting, Offices of the Institution of Engineers and Shipbuilders in Scotland, Glasgow.

25–26, Sept.
INSTITUTE OF PHYSICS AND PHYSICAL SOCIETY—Electron Jubilee Celebrations, London.

TRANSLATION SERVICE

Since the announcement made in the July issue of the *Journal* (*see* page 434), further translations have been put in hand and the following are now available or in course of preparation:

TRANSLATIONS AVAILABLE

No. 315 (German). F. KÖRBER and W. OELSEN: "The Action of Carbon as a Reducing Agent in the Reactions of the Steel-making Processes with Acid Slags." (*Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung*, 1935, vol. 17, No. 4, pp. 39–61).

No. 316 (Russian). V. V. KONDAKOV: "Steel-Melting Trials with Oxygen-Enriched Blast in the Bessemer Converter at the Stalin Kuznetzk Metallurgical Combine." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1401–1420).

No. 317 (Russian). A. C. HEINMAN: "Molecular Constitution of Open-Hearth Slags and the Distribution of Oxygen and Sulphur in the Slag-Metal System." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1439–1458).

No. 318 (Russian). YA. B. ZELDOVICH and N. V. SEMENOV: "Kinetics of Chemical Reactions in Flames." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, No. 9–10, pp. 1116–1136).

TRANSLATIONS IN COURSE OF PREPARATION

(German). G. BULLE: "The Production of Pig Iron with Low-Iron Burdens." (*Stahl und Eisen*, 1947, vol. 66–67, Mar. 27, pp. 69–78).

(German). A. GELEJI: "The Theoretical Problems Involved in the Design of Rolling-Mill Stands." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 224–242).

(German). A. GELEJI: "Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 208–223).

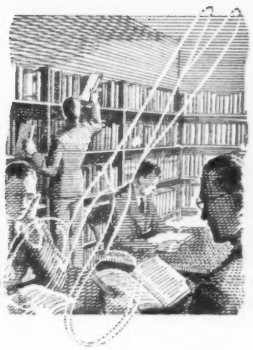
(Russian). M. A. GLINKOV and V. C. KOTCHO: "On the Question of Heat Transfer in a Molten Gas by Gas Bubbles." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1463–72).

(Russian). F. F. VITMAN, N. N. DAVIDENKOV and N. A. ZLATIN: "Cold-Brittleness of Steel in Torsion." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, Nos. 9–10, pp. 1137–1145).

CHARGES FOR COPIES OF TRANSLATIONS.—For the above translations a charge will be made of 10*s*. for the first copy and 5*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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FUEL—PREPARATION, PROPERTIES, AND USES

Russian Programme for Steam Plant Research. (Engineering and Boiler House Review, 1947, vol. 62, Jan., pp. 24–27, 32). The provisions made in the Russian Five-Year Plan for the reconstruction and development of the country's power supply are outlined. The programme drawn up by the All-Union Thermo-technical Institute covers research into the design of high- and super-pressure steam turbines and boilers, furnace operation, water-treatment, flue-gas cleaning, gas turbines, and the development of high-temperature alloys.—C. O.

Automatic Control. J. E. O'Breen. (Society of Instrument Technology : Blast Furnace and Steel Plant, 1947, vol. 35, Feb., pp. 236–238, 255 ; Mar., pp. 392–394). In the first part of the article air-operated boiler-house control gear is discussed. In the second part a description is given of a control system for pulverized-coal-fired boilers, in which the coal feed is regulated by varying the speed of the crushing mill in direct relation to the steam pressure in the boiler, whilst the air flow is governed by the steam output of the boiler. The importance of instrumentation independent of the controlling mechanisms is emphasized.—C. O.

The Problem of the Optimum Shape of the Surfaces of Heat Exchangers. H. Kühne. (Technik, 1947, vol. 2, Mar., pp. 127–131). Methods of calculating the dimensions and shape of heat-exchanger surfaces are discussed with a view to combining economy in materials with efficiency of heat transfer.—R. A. R.

The Application of Heavy-Media Separation and Static Dry Cleaning of Coal at the Broken Hill Pty. Co., Ltd. Steelworks, Newcastle. W. H. Wainwright and C. H. Martin. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1946, No. 141, Mar. 31, pp. 1–30). After a short outline of the principles of coal cleaning, a detailed description is given of the plant at the Newcastle works of the Broken Hill Proprietary Co., Ltd., which cleans the coal for the coke-ovens at a rate of 300 tons/hr. The plus 1-in. material is cleaned by the Barvoys process, using blast-furnace flue dust as the separating medium. The minus 1-in. material is cleaned by stratification brought about by introducing air at a constant pressure underneath a moving coal bed.—C. O.

The Operation of Froth Flotation Plant on Washery-Water Solids. W. J. Parton and C. D. Rubert. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2199 : Coal Technology, 1947, vol. 2, May). A description is given of a flotation plant at a Pennsylvania colliery for recovering fine anthracite which is discharged from the cleaning plant with the washery water.—R. A. R.

Flotation Treatment of Washery Water at the Empire, Alabama, Mine of the DeBardelen Coal Corporation. B. W. Gandrud and H. L. Riley. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2205 : Coal Technology, 1947, vol. 2, May).

Pulverised Fuel As a Boosting Agent in Melting Furnaces. N. H. Turner. (Institute of Fuel, Conference on Pulverised Fuel, 1947, June 2–6, pp. 552–557). A description is given of equipment for supplying pulverised fuel to increase the luminosity of the mixed gas flame heating a 250-ton steel furnace. The effect is to produce a very luminous flame, well-defined for about two-fifths of the length of the furnace, as well as to reduce slag-foaming.—R. A. R.

Coke Ovens in the Ruhr and Watenstedt Districts. (Combined Intelligence Objectives Sub-Committee, 1947, File No. XXXIII–55 : H.M. Stationery Office). A short survey is made of coke-oven practice in the Ruhr district and at Watenstedt. This report forms Appendix No. 2 to C.I.O.S. Report XXXII–119.—C. O.

Producer Gas Development. B. Evans. (Contact, 1947, vol. 7, Feb. ; British Chemical Digest, 1947, vol. 1, Apr., pp. 272–273). The R. D. Woods S.B.9 gas machine, developed in 1945, which gasifies 33 cwt. of coal per hour, is described. The operation, from feeding to ash removal, is fully mechanical ; blast is supplied by a turbo-blower, and the water-vapour content is closely controlled. The steam supply is automatically adjusted to give a constant gas pressure.—M. A. V.

The Theory and Practice of Producer Gas Manufacture in the Steelworks. M. L. Hughes. (Man and Metal, 1947, vol. 24, May, pp. 70–71). The chemical principles underlying the manufacture of producer gas suitable for firing open-hearth furnaces are outlined.—M. A. V.

The Manufacture of Oxygen in Large Quantities for Industrial Uses. M. J. Conway. (Iron and Steel Engineer, 1947, vol. 24, Mar., pp. 53–58). Methods and costs in commercial processes for the production of oxygen are discussed, with special reference to the applications of oxygen in the iron and steel industry.—J. R.

German Acetylene Chemical Industry—Ethylene from Acetylene, Coke-Oven Gas and Ethane. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1058 : H.M. Stationery Office). A report is made on the production of ethylene by the hydrogenation of acetylene. Descriptions are given of the ancilliary separation plant, together with information on the separation of crude ethylene mixtures from coke-oven-gas fractionations, the oxygen and thermal cracking of ethane to ethylene, the drying of ethylene, and the operation of the Linde plants at Gensdorf.—C. O.

REFRACTORY MATERIALS

Proceedings of the Twenty-Ninth National Open-Hearth Conference. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, 1946, vol. 29, pp. 262–293). The eight abstracts which follow cover the contributions to the Session on " Progress in Refractories and Masonry."—R. A. R.

Progress Report—Basic Furnace Construction. A. K. Moore. (*Ibid.*, pp. 262–264). The construction of a 180-ton open-hearth furnace with an all-basic lining is reported. An increase of 12·5% in the annual production of steel as compared with a silica furnace, and an increase in cost of about 7 cents/ton of steel are to be expected.—R. A. R.

Progress Report on Basic-End Furnaces. C. R. FonDersmith. (*Ibid.*, pp. 264–268). Data on the cost and performance of an open-hearth furnace with basic-brick ends are reported.—R. A. R.

Basic Refractories in German Open-Hearth Furnaces. G. E. Seil. (*Ibid.*, pp. 269–270).—R. A. R.

Design and Construction of Plastic-Lined Doors. J. N. Hornak. (*Ibid.*, pp. 271–279). Tests on open-hearth doors made with rammed refractory material supported by studs of various sizes are described. The rammed doors had a longer life than brick doors. Studs ½ in. in dia. at 3 in. centres, welded to a water-cooled plate, gave the best support and lasted as long as ¾-in. studs.—R. A. R.

Life of Basic Rammed Doors. G. N. Lawton. (*Ibid.*, pp. 279–280). Experience gained with basic-rammed furnace doors is recorded. Their life was 18 times greater than that of brick-lined doors ; their initial cost was greater, but the maintenance charges were very much less.—R. A. R.

Relation of Insulation to Fuel Economy. G. C. Primm. (*Ibid.*, pp. 286–287). Some advantages resulting from insulating open-hearth furnaces are discussed.—R. A. R.

Insulation and Fuel and Refractory Consumption. J. M. Brashear. (*Ibid.*, pp. 288–291). A gun for blowing insulating material on to open-hearth furnaces is described and data on the costs and advantages of insulation are given.—R. A. R.

Special Nozzles. E. C. Hite. (*Ibid.*, pp. 292–293). Experience obtained in the use of various ladle nozzles is recorded.—R. A. R.

Progress in Modern Steel Works Layout. A. G. Arend. (British Steelmaker, 1947, vol. 13, pp. 250–253). Improvements in the layout, equipment, and control methods in modern South African steelworks are described.—J. R.

The Basic Bessemer Plant and Steel Making Practice at Reichswerke A.G. Braunschweig. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1199 : H.M. Stationery Office).—R. A. R.

Metallurgical Developments in Japanese Ordnance. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./402 : H.M. Stationery Office). An account is given of the expedients used by the Japanese to overcome the shortages of materials in making ordnance.—C. O.

Use of Fuel Oil in Open-Hearth Furnaces. J. M. Ferguson. (West of Scotland Iron and Steel Institute : Iron and Coal Trades Review, 1947, vol. 154, May 2, pp. 787–790). The plant and production experiences on an open-hearth furnace adapted for oil-burning at the Dalzell Works of Messrs. Colvilles, Ltd., are described. —J. R.

Reactions in Acid Steel-Melting Processes. H. O. Howson. (Iron and Coal Trades Review, 1947, vol. 154, May 16, pp. 879–883 ; May 23, pp. 937–941). The views of the author regarding the mechanism of the acid steelmaking processes, based on practical experience, are put forward. It is suggested that the primary influence in the determination of the progress of the acid-furnace charge is the reaction between the metallic bath and the furnace hearth. The effects of alloying elements in acid-furnace reactions, the Tropenas process, and the acid-electric process, and the influence of silica reduction on steel quality are discussed.—J. R.

Steelmaking. R. H. Pullen. (Port Talbot Metallurgical Society : Iron and Steel, 1947, vol. 20, Apr., pp. 129–131). The more common aspects of the physical chemistry of steelmaking are outlined in non-technical language, and some of the problems encountered in fixed-type basic open-hearth-furnace practice are discussed.—J. R.

Steelmakers Weigh Oxygen Possibilities. (Iron Age, 1947, vol. 159, May 1, pp. 50–53, 133). The proceedings of the Thirtieth Conference of the National Open Hearth Steel Committee and Coke Oven, Blast Furnace and Raw Materials Committee of the American Institute of Mining and Metallurgical Engineers are briefly reported. —R. A. R.

Electrical Features of a Modern Hot-Metal Mixer Installation. W. A. Mosteller and L. R. Milburn. (Iron and Steel Engineer, 1947, vol. 24, Apr., pp. 65–69). The important electrical features of a 28-ft. dia., 36-ft. long, hot-metal mixer of 136 tons capacity, installed at the Ecorse Plant of the Great Lakes Steel Corporation, are described.—J. R.

A Remote Control Switch for Rocking Electric Melting Furnaces. R. J. Lean. (Machinery, 1947, vol. 70, May 1, pp. 457–462). A remote-control apparatus for rocking arc or resistance furnaces of any size is fully described. The electrical layout and the mechanism are shown diagrammatically, and its capabilities in automatically varying the rocking movement and time, are depicted.—R. L. B.

Adapts Pilot Plant to Manufacture of Alloy Steel. W. W. Stephens and J. L. Morning. (Steel, 1947, vol. 120, May 5, pp. 116–122). A description is given of a 4-ton electric furnace and auxiliary equipment at Shasta Dam, California, which is now used by the Bureau of Mines to test the possibilities of producing alloy steels from ores found near the West Coast.—R. A. R.

Pacific Northwest Plant Rolls Merchant Bars. G. E. Stedman. (Steel, 1947, vol. 120, May 12, pp. 128–132). A description is given of the electric steel furnace plant and rolling mills of the Hesse-Ersted Iron Works, Portland, Oregon.—R. A. R.

Economy in Electric Arc Furnace Operation. T. S. Winters. (Steel, 1947, vol. 120, Apr. 14, pp. 108–113). The economies which may be effected by the use of an automatic control for the maximum current demand by an electric-arc furnace are discussed.—C. O.

Specially Processed Silicon Carbide as a Deoxidizing Agent in the Reducing Slag of Basic Electric Steelmaking. E. A. Loria, H. D. Shephard, and A. P. Thompson. (Electrochemical Society, 1947, Preprint No. 91–18). The addition of special-quality granular silicon carbide with the finishing slag in basic electric steelmaking is recommended. Owing to its greater reactivity this addition is superior to the product formed in ordinary steelmaking practice by the interaction of coke, lime, and ferrosilicon.—D. R. S.

Electric Steel in the United States at Forty-One. C. G. Merritt. (Electrochemical Society, 1947, Preprint No. 91–14). The development of electric steelmaking in the United States since its inception 41 years ago is outlined, with special reference to the conditions during and since the 1939–1945 war.—D. R. S.

Improvements in Ingot-Mould Design. W. Ash. (Iron and Coal Trades Review, 1947, vol. 154, May 30, pp. 993–995). A description is given of improved designs of ingot moulds for bottom pouring. Adoption of the designs discussed has resulted in the overcoming of stripping difficulties, a reduction in stripping times, an increase in mould life, and a saving in costs.—J. R.

PRODUCTION OF STEEL

Proceedings of the Twenty-Ninth National Open-Hearth Conference. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, 1946, vol. 29). The Conference was held on April 25 and 26, 1946, in Chicago. It was attended by 792 representatives of the steel industries of the United States, Canada, Mexico, Australia, Russia, and South Africa. Apart from the presentation of the paper which received the McKune award, the Conference was held in six sessions dealing with (*a*) basic open-hearth operations, (*b*) basic and acid open-hearth repairs and maintenance, (*c*) metallurgy of the basic process, (*d*) quality in the basic process, (*e*) progress in refractories and masonry, and (*f*) operations and quality in the acid open-hearth process. Abstracts of the contributions to the Conference follow.—R. A. R.

A Statistical Method and Results of a Study of Factors Affecting Open-Hearth Production Rate. A. P. Woods and C. R. Taylor. (*Ibid.*, pp. 15–31). This paper gained the McKune Award for the best paper submitted to the Conference. (An abstract has already appeared, *see* Journ. I. and S.I., 1946, No. II, p. 89A).

Effect of Charging Rate on Production. V. W. Jones. (*Ibid.*, pp. 32–35). The effect of the time taken in charging on the production rate of an open-hearth furnace is discussed. When more than 2 hr. elapsed between finish-charging of the scrap and the hot-metal addition the production rate fell rapidly.—R. A. R.

Charging Practice at Republic Steel Corporation South Chicago. M. J. Miller. (*Ibid.*, pp. 33–37). The results are shown of studies of the influence of charging time on the total time of basic open-hearth furnace heats with cold charges.—R. A. R.

Study of Charging Rate at South Works. J. F. O'Brien. (*Ibid.*, p. 37). Data on the effect of different charging times on the rate of production in open-hearth furnaces are discussed.—R. A. R.

Effect of Charging Rate on Production. V. Gregor. (*Ibid.*, pp. 39–40). Scrap charging and hot-metal charging at the Gary Works of the Carnegie-Illinois Steel Corporation are described.—R. A. R.

Practice at Youngstown Sheet and Tube Co. H. J. Darlington. (*Ibid.*, pp. 40–41). Data on the variation in tons per hour of steel produced in relation to different charging times are presented and discussed.—R. A. R.

Advantages of Change from Double to Single Checkers. L. A. Lambing. (*Ibid.*, pp. 41–42). Some advantages resulting from the combining of two checker chambers at each end of 175-ton and 225-ton furnaces into one larger chamber at each end, when using tar as fuel, are described.—R. A. R.

Two-Checker Construction Preferred at Republic Steel Corporation. H. L. Allen. (*Ibid.*, pp. 42–43). Data are presented comparing the production over four years of two double-checker-chamber furnaces with that of one single-chamber furnace. They indicate that the single-chamber furnace did not produce a greater tonnage per hour or decrease the fuel consumption.—R. A. R.

Limestone and Lime of Open-Hearth Quality. D. E. Washburn. (*Ibid.*, pp. 44–46). The occurrence of silica and sulphur in limestone, and calcining in rotary kilns are discussed.—R. A. R.

Use of Small-Size Limestone. I. A. Nicholas. (*Ibid.*, pp. 46–47). The effects of the use of limestone of different sizes in the open-hearth furnace are considered. Tests indicated that small limestone up to 2 in., provided it is free from dust, does not cause a "blow up" during the lime boil.—R. A. R.

Limestone Solution in the Basic Open-Hearth Furnace. M. Tenenbaum and J. S. Griffith. (*Ibid.*, pp. 47–56). The mechanism of limestone solution and the reactions leading to the formation of a shell of dicalcium silicate on limestone lumps in the steel bath are discussed in the light of a study of the petrography of lumps removed from an open-hearth furnace after making the hot-metal addition.—R. A. R.

Desulphurization of Pig Iron by Additions of Soda Ash. C. L. Labeka. (*Ibid.*, pp. 56–58). Methods of adding soda ash to desulphurize pig iron and precautions to be taken in preparing the iron for the open-hearth furnace are described.—R. A. R.

Desulphurizing Cupola Iron. W. H. Steinheider. (*Ibid.*, pp. 58–60). Tests on the efficiency of various methods of desulphurizing cupola iron with soda ash to prepare it for the open-hearth furnace are described.—R. A. R.

Substitution of Coke for Pig Iron in Open-Hearth Charge. O. P. Luetscher. (*Ibid.*, pp. 60–64). Experience gained in the use of coke instead of pig iron in open-hearth furnaces is related. The extent to which coke can be used depends primarily upon the silicon content of the charge. Large additions of coke substantially increase the time of heats, whilst the heat time is unaffected by the form of the carbon.—R. A. R.

Substitution of Coke for Pig Iron in Open-Hearth Charge. E. H. Schwartz. (*Ibid.*, pp. 64–65). An experiment in the substitution of coke for part of the iron charge in open-hearth furnaces is reported. The experiment was successful and it was shown that the heat could be controlled as accurately as when normal iron charges were used.—R. A. R.

Summary of Questionnaire on Time of Preliminary Tests. J. R. Pigott. (*Ibid.*, pp. 65–67). The results are summarized of 41 replies received in answer to a questionnaire on the time required for determining the carbon, manganese, sulphur, phosphorus and the common alloying elements for open-hearth control purposes.—R. A. R.

Labour-Saving Devices in the Open-Hearth. B. D. McCarthy. (*Ibid.*, pp. 68–71). The Mechanical equipment used in the repair and maintenance of open-hearth furnaces is described.—R. A. R.

Labour-Saving Devices Used at Bethlehem Steel Company. T. A. Lewis. (*Ibid.*, pp. 72–78). The equipment and methods used for re-building open-hearth furnaces are described.—R. A. R.

An Improved Method of Removing Open-Hearth Slag. L. P. Lias. (*Ibid.*, pp. 78–81). A method of removing slag in one large block from slag pockets is described.—R. A. R.

Cleaning Checkers and Flues. L. B. Luellen. (*Ibid.*, pp. 84–85). The cleaning of Smalley checker chambers by blowing with steam once every seven days is described.—R. A. R.

Using the Zimmerman Vacuum Unit. J. E. Smith. (*Ibid.*, p. 86). The cleaning of checker chambers by blowing with steam and using the Zimmerman flue-dust conveyor is described.—R. A. R.

Behavior of Various Types of Open-Hearth Bottoms in Service. R. B. Snow. (*Ibid.*, pp. 87–92). An investigation of the characteristics of rammed and of sintered open-hearth bottoms is reported. Samples were taken from the hearths during service, using a hollow diamond-tipped drill, and the nature of these samples was carefully examined.—R. A. R.

Comparison of Fully Rammed Bottoms, Partly Rammed Bottoms with Burned-In Top Surface, and Fully Burned-In Bottoms. B. D. McCarthy. (*Ibid.*, pp. 93–95). Data are presented and compared on the fettling time between heats for open-hearth furnaces with hearths prepared in different ways.—R. A. R.

Experience with Sintered and Rammed Bottoms at Wisconsin Steel Works. E. H. Schwartz. (*Ibid.*, pp. 98–102). A comparison of the merits of rammed and sintered open-hearth bottoms is made. The rammed-bottom furnaces were ready for steel about 13 days sooner than those with a sintered bottom, and the construction costs of the former were slightly less.—R. A. R.

Inverted Arch Basic Brick Bottoms. H. M. Kraner. (*Ibid.*, pp. 104–111). Full details are given of the design and construction of an open-hearth furnace, the bottom of which was curved to a radius of 14 ft.; it was made of chrome-magnesite refractories with a layer of 3–4 in. of sintered magnesite on top.—R. A. R.

Fettling and Bottom Maintenance. J. E. Smith. (*Ibid.*, pp. 114–115). After resurfacing the hearths of three open-hearth furnaces with Michigan regular-grain magnesite, the Republic Steel Corporation found that there was a saving of time in repairs between heats.—R. A. R.

Maintenance of Slag Thimbles and Cars. E. H. Leathers. (*Ibid.*, pp. 116–118). The inspection and repair of slag thimbles and cars is described.—R. A. R.

Maintenance and Inspection of Crane Hoist Cables. L. A. Lambing. (*Ibid.*, p. 119).

Some Factors Affecting Excess Air Requirements in the Melting Chamber. M. Tenenbaum and J. M. Brashear. (*Ibid.*, pp. 121–132). Gas-analyser equipment for the continuous determination of the oxygen in the waste gas from open-hearth furnaces is described, and the factors governing the most efficient fuel/air ratio are discussed.—R. A. R.

Slag Metal Relations of Phosphorus Elimination. T. B. Winkler and J. Chipman. (*Ibid.*, pp. 133–136). *See* Journ. I. and S.I., 1946, No. II, p. 49A.—R. A. R.

Sulphur Equilibria between Slag and Metal. N. J. Grant and J. Chipman. (*Ibid.*, pp. 140–146). *See* Journ. I. and S.I., 1946, No. II, p. 49A.—R. A. R.

Practical Sulphur Elimination. H. B. Emerick. (*Ibid.*, pp. 146–147). The methods used by the Jones and Laughlin Steel Corporation to remove sulphur from the bath of the open-hearth furnace are described.—R. A. R.

Problem of Desulphurization and Its Solution. T. E. Brower. (*Ibid.*, pp. 147–149). The distribution of sulphur between slag and steel during refining is discussed and the desulphurization practice of the United States Steel Corporation is described.—R. A. R.

Influence of Hot-Metal Composition on Sulphur in Steel. C. T. Stott. (*Ibid.*, pp. 149–151). Graphs showing the content of sulphur in the finished steel when charging 55–60% of hot metal with 8% of limestone are presented. It is shown that with increasing sulphur in the hot metal the percentage of sulphur in the steel increases at a still greater rate.—R. A. R.

Influence of Operating Variables on Ladle Reactions in Low-Carbon Rimmed Steel (0·10 Per Cent Carbon or Under). P. W. Nutting and C. C. Brown. (*Ibid.*, pp. 152–157). An attempt was made to determine the factors in open-hearth practice which caused ladle reactions in the production of 0·10% carbon rimming steel. A "reaction heat" was one in which samples taken from the second and from the last-but-one ingot showed a drop in the manganese of more than 0·06%. The data obtained indicated that reaction heats were associated with: (*a*) A slower rate of fall in the carbon content in the finishing stages of the heat; (*b*) a higher FeO content in the finishing slag; (*c*) low manganese in the bath on tapping; and (*d*) larger additions of aluminium to the moulds.—R. A. R.

Oxygen in Liquid Open-Hearth Steel—Oxygen Content during the Refining Period. T. E. Brower and B. M. Larsen. (*Ibid.*, pp. 162–176). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 303).—R. A. R.

Grain-Growth Inhibitors in Steel. J. W. Halley. (*Ibid.*, pp. 187–197). *See* Journ. I. and S.I., 1946, No. II, p. 122A.—R. A. R.

Open-Hearth Practice to Meet Hardenability Requirements. A. G. Forrest and J. V. Russell. (*Ibid.*, pp. 200–206). The manner in which open-hearth practice can be adjusted to produce steel with a specified hardenability is discussed.—R. A. R.

Cast Hardenability Tests. E. W. Pierce. (*Ibid.*, pp. 207–210). A procedure is described for the rapid casting in the melting shop of specimens to be tested for hardenability.—R. A. R.

Melting to Hardenability. E. A. Reid. (*Ibid.*, pp. 211–214). A table of factors for calculating the effect of many elements on the hardenability of steel is presented and an example of its use is described.—R. A. R.

Cast Jominy Tests for Determining Hardenability. H. B. Wishart. (*Ibid.*, pp. 214–221). To control the hardenability of steel during production a rapid casting method for Jominy specimens was developed. The procedure is described and the results obtained are compared with those obtained on forged specimens cast from the ladle.—R. A. R.

Summary of Questionnaire on Deoxidation of Semi-killed Steel. M. Tenenbaum. (*Ibid.*, pp. 222–226). The answers received from 34 steelworks in reply to a questionnaire on deoxidation practice for making semi-killed steel are analysed.—R. A. R.

A Radiation Pyrometer for Open-Hearth Bath Measurements. H. T. Clark and S. Feigenbaum. (*Ibid.*, pp. 229–241). *See* Journ. I. and S.I., 1946, No. II, p. 114A.—R. A. R.

Thin-Walled Moulds. M. F. Yarotski. (*Ibid.*, pp. 248–249). The results obtained with two types of ingot mould are compared. Both types measured 25 × 25 × 67 in., but the wall thicknesses were different. There were more cracks at the bottom of ingots from the thin-walled moulds.—R. A. R.

Plain, Rippled, Fluted and Corrugated Molds. J. R. Brady. (*Ibid.*, pp. 249–251). Experience gained at the Wisconsin Steel Works in the use of ingot moulds of different design is related.—R. A. R.

Inverted Solid-Bottom Molds. G. H. Warnock. (*Ibid.*, pp. 251–252). Experience gained over a long period with solid-bottom ingot moulds measuring 24 × 64 × 69 in. showed that the number of "stickers" was much less than with plug-closed moulds.—R. A. R.

Mold Coatings.—Pitch-Coated Ingot Molds. J. T. Mauer. (*Ibid.*, p. 253). The reconditioning costs of pitch-coated ingot moulds were found to be much less than those of tar-coated moulds, but a method has to be found for preventing the powdered pitch from irritating the skin of the operators.—R. A. R.

Technique for Improving Low-Carbon Killed Steel of Carburizing Grades. L. W. Fleming. (*Ibid.*, pp. 255–257). Measures to improve the quality of low-carbon killed steel are discussed. With oil-fired furnaces the sulphur content of the oil should not exceed 0·70%.—R. A. R.

Improving Surface Quality of Rimmed Steels with 0·20 Per Cent Carbon. I. A. Sirel. (*Ibid.*, pp. 258–259). A technique for producing low carbon rimming steel is described; it includes an addition of 4 oz. of sodium fluoride per ton in the mould to promote a good rimming action.—R. A. R.

Results Obtained by Improved Furnace Design. E. E. Callinan. (*Ibid.*, pp. 295–297). A description is given of the improvements to the design of a 65-ton acid open-hearth furnace which resulted in an increase of 12% in the production per hour.—R. A. R.

Control of Acid Open-Hearth Heats through Measurements of Slag Fluidity. J. W. Linhart. (*Ibid.*, pp. 299–308). Descriptions are given of the Herty and "AOHRA" (Acid Open-Hearth Research Association) viscometers for slag and a method of controlling low-carbon acid open-hearth heats by slag-fluidity tests is outlined.—R. A. R.

Superheated Air *vs.* Superheated Steam for "Atomization" of Fuel Oil. A. R. Altman. (*Ibid.*, pp. 313–315). A comparison is made of the performances of two acid open-hearth furnaces, one with superheated air to atomize the fuel oil and the other with superheated steam.—R. A. R.

FOUNDRY PRACTICE

Foundry Practice in Argentina. E. J. Ash. (Foundry, 1947, vol. 75, Jan., pp. 72–73, 182–187). A short survey is made of the foundry industry of Argentina. Most of the founding in the country is carried on in small jobbing works, but there are a few large concerns in the Buenos Aires district employing as many as 500 men. Raw materials are mainly imported, pig iron from Brazil and coke from South Africa and the United States; home-produced petroleum coke and charcoal are also used. Native "*tierra colorada*" and bentonite are the sources of the moulding sands.—C. O.

Some Problems in Cast Iron. E. Piwowarsky. (Iron Age, 1947, vol. 159, Jan. 9, pp. 58–60). The results of some wartime investigations in Germany, Switzerland, and Russia on hot-blast cupolas, special melting units, rolled cast iron, heat- and scale-resistant iron, and armoured iron are discussed.—C. O.

Desulphurization and Dephosphorization of Molten Cupola Iron and Pig-Iron in Basic-Lined Ladles. (Institute of British Foundrymen; Foundry Trade Journal, 1947, vol. 81, April 3, pp. 259–267). This paper is a report by Sub-Committee T.S. 10 of the Institute of British Foundrymen, which was appointed in 1944 to examine the possibilities of reducing the phosphorus and sulphur contents of iron by the use of basic-lined cupolas and by treatment in the ladle. Recent experience with the desulphurization of molten metal by adding soda ash in the ladle is summarized. Using basic-lined ladles and a double-pouring technique, it has been found possible to reduce an initial sulphur content of 0·20% to 0·045%; a reduction of 75–80% can be obtained consistently with 5-ton samples. It was discovered that during the desulphurization of a low-silicon cast iron, an appreciable amount of phosphorus was also removed. In a full-scale trial the phosphorus content of a low-silicon cupola-melted iron was reduced by 20% from 0·045% by the addition of sodium carbonate plus an oxidizing agent.—C. O.

The Cupola. J. S. Abcouwer. (Metalen, 1947, vol. 1, Feb., pp. 93–99; Mar., pp. 118–122). (In Dutch). The theory and practice of cupola operation are discussed. It is shown how to calculate the melting rate from the coke-burning rate and iron/coke ratio, and the problem of determining how much of the total heat generated is transmitted to the molten iron is considered.—R. A. R.

Utilization of High Sulphur Coke in Foundry Practice. (Council of Ironfoundry Associations: Foundry Trade Journal, 1947, vol. 81, Mar. 20, pp. 217–219). Methods of reducing the sulphur content of the iron when using high-sulphur coke in the cupola are discussed. The best method is to charge a high-manganese iron. The highest sulphur pick-up occurs in the first taps of a heat; it can be reduced by charging flux on to the coke bed. When good low-sulphur coke is available it should be reserved for use in the bed only.—R. A. R.

Slagging Gas Producer for Melting Foundry Iron. H. La Planche. (Metal Progress, 1947, vol. 51, Mar., pp. 447–450). A description is given of the use in France, to overcome the shortage of metallurgical coke, of the gas-producer cupola, which is in effect a closed-top shaft furnace with hot blast. A high-strength iron and gas for other heating operations can be produced simultaneously. It is suggested that "slagging gas producers" may be used for melting metal for refining in open-hearth or electric furnaces.—C. O.

Malleable Cast Iron. H. G. Hall. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 81, Jan. 16, pp. 53–57; Jan. 23, pp. 75–79; Jan. 30, pp. 99–104). A summary of the existing knowledge on the

subject of maleablizing cast iron by both the whiteheart and blackheart methods is presented, in order to show the need for further research before the industry can be modernized.—C. O.

Modern Melting Methods for Malleable Foundries. W. R. Jaeschke. (Chicago Regional Foundry Conference: Foundry, 1947, vol. 75, Mar., pp. 72–75, 202–216). An account is given of the development of the duplex system of melting in malleable iron foundries. Descriptions are given of the operation of the cupola/electric-furnace and the cupola/air-furnace systems. Mention is made of the removal of slag from cupolas by sluicing with water, pre-heated blast, and pulverized-coal firing.—C. O.

Acid Electric Melting. N. F. Dufty. (British Steelmaker, 1947, vol. 13, Feb., pp. 80–86). Electric furnace practice in the steel foundry, using small acid-lined furnaces, is described in detail.—R. A. R.

Producing Large Steel Castings. P. Dwyer. (Foundry, 1947, vol. 75, Feb., pp. 74–77, 224–226). The equipment and technique employed by the Bethlehem Steel Company for making very large steel castings are described and illustrated.—R. A. R.

The Engineer Looks at Sand Problems. E. E. Woodliff. (Foundry, 1947, vol. 75, Feb., pp. 66–67, 182–190). The optimum mixtures of sand, clay, and moisture for moulding sands for different types of casting are discussed. To obtain a minimum of expansion or contraction a mixture of silica 88% with clay substance 12% is recommended. The use of seacoal and other combustible binders is also considered.—R. A. R.

Foundry Sand Produced near Eugene Oregon. W. D. Lowry. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2058: Mining Technology, 1947, vol. 11, Mar.). The geology, preparation and properties of the steel foundry sand produced near Eugene, Oregon are described.—R. A. R.

Sands for Heavy Steel Castings. D. J. Taylor. (American Foundrymen's Association: Foundry, 1947, vol. 75, Mar., pp. 106–107, 129). The heat-transfer characteristics, spalling resistance, and chemical composition of mouldings sands for heavy steel castings are discussed.—C. O.

A Hardness Tester for Moulding Sand. L.-B. Lindh and S. Thrysin. (Teknisk Tidskrift, 1947, vol. 77, Mar. 8, pp. 233–235. (In Swedish). A simple apparatus for determining the "flow point" of moulding sands is described. The indenter is the flat end of a small cylindrical bar the upper end of which is screwed into a dial gauge. A lever system with a sliding weight rests upon the upper spindle of the gauge. The load on the indenter is increased at 30-sec. intervals by moving the weight along the beam and a load/impression-depth curve is drawn. The flow point is the band at which the straight-line relationship ceases—R. A. R.

Ventilating Screens, Breakers, Mullers. (Foundry, 1947, vol. 75, Mar., pp. 76–77, 229–231). Methods of controlling and removing the dusts formed during the continuous circulation of sand in a mechanized foundry are described and illustrated.—C. O.

Refractory Coatings for Permanent Molds. H. E. Bourassa. (Iron Age, 1947, vol. 159, Feb. 6, pp. 58–59). The selection and application of a refractory coating for permanent moulds are briefly discussed.—C. O.

Selection and Application of Mold- and Core Blackwashes. E. E. Thews. (British Intelligence Objectives Sub-Committee, 1946, F.I.A.T. Final Report No. 877: H.M. Stationery Office). The defects in castings resulting from the use of a blackwash of the wrong composition are discussed. The importance of selecting the correct type of wash for a specific application and of thorough mixing before use are emphasized.—C. O.

Patternmaking. B. Levy. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 81, Mar. 27, pp. 239–244). A new machine for the cutting of irregular shapes necessary in patternmaking is described, and the advantages to be expected from its use are enumerated.—J. R.

Applying Good Management in the Pattern Shop. G. M. Dexter. (Foundry, 1947, vol. 75, pp. 68–71, 215–224).

Rubber Mountings Minimize Impact from Jolt Molding Machines. H. J. Knell. (Iron Age, 1947, vol. 159, Feb. 20, pp. 54–56). The use of rubber mountings to minimize the vibration in surrounding areas caused by the operation of jolt moulding machines is described.—C. O.

Modern Improvements in the Chilled Car Wheel. L. H. Rudesill. (Kansas City Car Foremen's Association: Foundry, 1947, vol. 75, Feb., pp. 84–87, 170–175). Improvements in the foundry practice for making chilled cast iron railway wagon wheels are described. These include using a metal recuperator to provide hot blast for the cupola, and inoculation with tellurium-graphite.—R. A. R.

The Production of Cast Crankshafts. R. B. Templeton. (Journal of the Institution of Automobile Engineers. 1947, vol. 15, Mar.–Apr., pp. 231–249). Problems of design, application, and production in the manufacture of cast crankshafts for automobiles are dealt with.—R. A. R.

Centrifugal Casting. L. Northcott. (Institute of British Foundrymen and Institute of Metals: Foundry Trade Journal, 1947, vol. 81, Feb. 13, pp. 151–155). True and semi-centrifugal casting, and casting by centrifuging are defined, and the equipment, process and its characteristics are described. Formulæ for calculating the relationships between rotational speed, centrifugal force and the pressure on the mould wall are presented.—R. A. R.

Mechanical Handling in the Foundry. W. M. Philip. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 81, Mar. 6, pp. 179–181).

HEATING FURNACES AND SOAKING PITS

Modern Industrial Electric Heating. A. E. Williams. (Mechanical World, 1946, vol. 120, Nov. 22, pp. 569–574; Nov. 29, pp. 602–606). Recently developed processes for applying electricity to industrial heating are reviewed. They may be divided into two groups: (1) Iso-electric heating, in which bare resistance heating elements are immersed in the material to be heated, such as oils, resins, paints, and plastics; and (2) radio-frequency heating, which is known as dielectric heating when applied to non-conductors, and as eddy-current or induction-heating when applied to conductors.—C. O.

Essential Considerations in Furnace Usage and Design. H. Southern. (Sheffield Metallurgical Association: Metallurgia, 1947, vol. 35, Mar., pp. 227–232). Factors affecting furnace efficiency are compared. Sixteen factors contributing to waste of fuel, and the selection and appraisal of fuels are considered, and examples of calculations relating to a reheating furnace fired with blast-furnace gas are given.—R. A. R.

Furnaces with Walls Permeable to Gas. G. Neumann. (Stahl und Eisen, 1947, vol. 66–67, Jan. 30, pp. 60–63). The design of the gas-fired furnace with inner walls permeable to gas described by R. H. Anderson, D. C. Gunn and A. L. Roberts (*See* Journ. I. and S. I., 1944, No. II, p. 108A) is critically discussed.—R. A. R.

The Infra-Red Gas Burner. L. Sanderson. (Metallurgia, 1947, vol. 35, Feb., pp. 187–189 ; Mar., pp. 239–240). A brief outline of the theory of infra-red radiation heating is given. A typical infra-red gas burner, in which a refractory bowl is maintained at a radiant heat by the combustion, and some infra-red burner applications are described.—R. A. R.

Induction Heating—Theory and Application of High Frequency Apparatus. E. May. (Institution of Production Engineers : Iron and Steel, 1947, vol. 20, Feb., pp. 77–80 ; Mar., pp. 117–120). **High Frequency Induction Heating.** E. May. (Machinery, 1947, vol. 70, Jan. 9, pp. 45–49). The theory, applications, and costs of high-frequency apparatus for induction heating are discussed. —J. R.

High Frequency Induction Treatment and Its Application to Ferrous Metals. R. J. Brown. (Staffordshire Iron and Steel Institute ; Sheet Metal Industries, 1947, vol. 24, Mar., pp. 598–602 ; Apr., pp. 793–796, 809). A short outline is given of the principles of electrical induction heating. Its applications in the ferrous-metal industries are discussed.—C. O.

High Frequency Heating. J. F. Capper. (Electrical Times, 1947, vol. 111, Apr. 17, pp. 417–421). The effects of variations in the loss factor of dielectric material during the heating process are described, and the advantages of automatic loading control are discussed.—J. R.

Economic and Practical Aspects of Electric Hoists for Operating Industrial Furnace Doors. F. J. Ryan. (Industrial Heating, 1947, vol. 14, Jan., pp. 48–54). The installation of electric door-fitting equipment on industrial furnaces has resulted in improved efficiency in a large number of plants. The economic and practical aspects are discussed and some advantages over manually operated doors are enumerated. Examples of its application are described.—G. C. J.

HEAT TREATMENT AND HEAT-TREATMENT FURNACES

The "S" Curve and Its Application to Industry. R. Atkin. (Australian Institute of Metals : Australasian Engineer, 1947, Mar. 7, pp. 75–82). The construction of **S**-curves and the influence of alloying elements on the shape and position of the curves are briefly explained. The principles of the austempering, martempering, and isothermal annealing processes are described.—C. O.

Fundamentals of Carburization and Decarburization of Steel. J. K. Stanley. (Steel, 1947, vol. 120, Apr. 14, pp. 92–96, 128–130). The theory of carburization and decarburization in industrial processes is discussed.—C. O.

The Carburizing of Steels As a Reaction in the Solid State. H. Stäger, E. Brandenberger, and E. Kobel. (Schweizer Archiv, 1947, vol. 13, Apr., pp. 97–113). An investigation is reported in which the carburizing effect of powders of different forms of carbon on small cylinders of 0·3% carbon steel was studied. Graphite and six forms of lamp black precipitated from gases were used ; they were first examined under the electron microscope and by X-rays. The steel cylinders were filled with these powders, some loose and others rammed, and held for 1 hr. at 1200° C. in a vacuum. There was a marked migration of carbon from the graphitic carbon into the steel, but there was no migration from the amorphous carbon powders. After graphitizing the powders at 2000° C., however, they acquired the ability to carburize. The effect of different graphitizing treatments on the particle size of carbon and the mechanism of the diffusion of the carbon into the steel were also studied.—R. A. R.

Controlled Furnace Atmospheres. A. G. Hotchkiss. (Steel Processing, 1947, vol. 33, Mar., pp. 151–156, 179 ; Apr., pp. 240–241). The chemical composition of heat-treatment furnace atmospheres and the factors causing oxidation, carburization, and decarburization are discussed. A unit for removing carbon dioxide, and an endothermic converter for the reaction of air and fuel gas to produce a reducing atmosphere are described.—R. A. R.

Woven Wire Conveyor Belts for High Temperature Service. F. L. Hooper. (Steel Processing, 1947, vol. 33, Mar., pp. 157–161). Applications of woven-wire conveyor belts made of plain-carbon, low-alloy, chromium–nickel steels, or nickel–chromium alloys, in furnaces operating at temperatures between 800° and 2100° F. and with a variety of atmospheres, are described. —C.O.

Heat Treating Fasteners by the Million. H. Chase. (Steel, 1947, vol. 120, May 5, pp. 104–106, 148). Equipment for the heat-treatment of large numbers of small pressings and stampings in gas-fired salt-bath furnaces with subsequent oil-hardening and tempering is described.—R. A. R.

Salt Baths for Metals. E. L. Cady. (Materials and Methods, 1947, vol. 25, Mar., pp. 99–114). This is a review of current practice and principles, and the characteristics of the salts employed in the heat-treatment of metals, especially steels, by the salt-bath method. The uses and reasons for using (and not using) salt baths are listed. Preparatory cleaning, drying, setting up, and the immersion of the work are described. The removal of the work and the cleaning of the salt from the work are discussed. Chemical effects during treatment, the stabilizing conditions of heat flow, the viscosity, specific gravity, and working ranges of the salt, and the thermal capacity of the salt bath, are mentioned as important items demanding attention during operation.

References are made to liquid case-hardening, the control of operational factors to produce a desired nitrided, carburized, or intermediately hardened case, size tolerances and distortion, shock resistance, and metallurgical control. Batch and continuous operation are depicted.—R. L. B.

German Flame Hardening of Armour Plate and Flame Cutting and Flame Hardening of Sprockets for Armoured Fighting Vehicles. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1263 : H.M. Stationery Office).—R. A. R.

Induction Hardening Steel Bars at J. & L. J. F. Wilson. (Iron Age, 1947, vol. 159, May 15, pp. 44–46). An illustrated description is given of the induction-hardening plant installed by the Jones and Laughlin Steel Corporation for the hardening of cold-finished steel bars in lengths of 10–24 ft. and up to $1\frac{1}{16}$ in. in dia.—R. A. R.

Basic Requirements of Materials for Induction Hardening. R. H. Lauderdale. (Product Engineering, 1947, vol. 18, May, pp. 110–115). The following factors governing the successful induction-hardening of steel are discussed : (*a*) Relation of electric power to size and shape of part ; (*b*) the microstructure and its response to the rapid rate of heating ; (*c*) relation of size and shape of part to rate of quenching ; (*d*) sufficiency of carbon ; and (*e*) internal stresses which control dimensional changes. —R. A. R.

Nitralloy Steels and the Nitriding Process. R. W. Allott. (Sheffield Engineering Trades Technical Society and the Sheffield Heat Treatment Technical Society : British Steelmaker, 1947, vol. 13, Apr., pp. 180–186 ; May, pp. 240–245). The history of research upon the

nitriding of steels is dealt with, and the process and its advantages are discussed.—J. R.

Recent Improvements in Cover Annealing. A. J. Fisher. (Iron and Steel Engineer, 1947, vol. 24, Apr., pp. 53–62). Although the development of the radiant-tube furnace for the cover-annealing of sheets and tinplate removed many difficulties encountered when the covers and bases were made up as portable units, certain disadvantages were inherent in the system. In view of these, direct firing for cover-annealing was studied at the Sparrows Point plant of the Bethlehem Steel Co. Results obtained on a direct-fired test furnace were encouraging, and, after a means for the protection of inner covers had been developed, 28 furnaces were converted from radiant-tube to direct firing.—J. R.

Heat-Treatment of Dies. E. F. Watson. (Machinery, 1947, vol. 70, May 8, p. 491). The composition and heat-treatment of steel dies for (*a*) hot stampings and pressings, (*b*) shearing and punching dies for steel sheets and pressings, (*c*) moulded products (plastics and clays), and (*d*) extrusion dies and mandrels, are described.—R. L. B.

FORGING, STAMPING, DRAWING AND PRESSING

40,000-Tons Forging Press and Other Hydraulic Plant. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1102 : H.M. Stationery Office).—R. A. R.

Effect of Forging on Segregation in High-Speed Steel. E. S. Kopecki. (Iron Age, 1947, vol. 159, Feb. 20, pp. 42–43). The distribution of carbides in an ingot of high-speed steel at various stages during its forging into a $1\frac{1}{8}$-in. square bar is shown by photomicrographs and radiographs.—C. O.

Designing, Drafting and Using Press Tools. C. W. Hinman. (Steel Processing, 1946, vol. 32, Nov., pp. 724–729 ; Dec., pp. 788–791). The selection of presses and the factors influencing the design of dies suitable for cutting large blanks from heavy steel plate are discussed. The operation of a press which fabricates one completed steel tube in each stroke is described in detail.—C. O.

Tough Stainless Demands Rugged Tooling. P. Hallin. (Machinist, 1947, vol. 90, Mar. 29, pp. 1999–2001). Some details of design and recommendations for the operation of press tools for the drawing, blanking, and punching of stainless steels are given and compared with those for mild steels. The available die materials and drawing compounds are reviewed.—R. L. B.

Manufacture and Manipulation of Tool Steels. H. W. Pinder. (Iron and Coal Trades Review, 1947, vol. 154, Jan. 31, pp. 221–224 ; Mar. 21, pp. 473–476 ; Apr. 11, pp. 635–636). In the first part the author discusses the heat-treatment and cogging of tool-steel ingots. High-carbon high-alloy steels which are prone to heavy structural segregation must be hammer-cogged in order to produce a uniform structure. Other types of steel may be cogged successfully by rolling. Hammer-cogging is described more fully in the second part which also deals with heating and forging practice. In the third part the inspection of billets, and the relation between the size of billets and blanks for forging and the reduction of segregation are discussed.—R. A. R.

Experiences in the Design of Drawing Dogs and Accessories for Multiple Bar Drawing. K. Wallmann. (Stahl und Eisen, 1947, vol. 66–67, Apr. 24, pp. 149–153). Descriptions are given of recent improvements in the design of drawing dogs and bar-gripping devices with special reference to dogs for drawing two bars at a time.—R. A. R.

German Ferrous Wire Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1214 : H.M. Stationery Office). A comprehensive survey is made of the ferrous wire industry in the British, American, and French Zones of Germany. Details are given of the practice at individual works.—C.O.

Technical Progress in the Wire Industry. R. S. Brown. (Wire Industry, 1947, vol. 14, Apr. pp. 203–207). After brief notes on the very early history of wire-drawing a more detailed account of developments from the advent of the tungsten carbide die in 1926 is given.—R. A. R.

ROLLING-MILL PRACTICE

Electrical Highlights in the Rolling Mill and Auxiliary Expansion during 1946. H. W. Poole. (Blast Furnace and Steel Plant, 1947, vol 35, Jan., pp. 85–88, 94). The post-war reconversion and expansion programme for the American steel industry included plans for the construction of new rolling mills and for modifications to existing plant. The electrical equipment for these installations is described.—J. R.

Rolling Loads. E. C. Larke. (Midland Metallurgical Societies : Metal Industry, 1947, vol. 70, Apr. 4, pp. 223–225 ; Apr. 11, pp. 243–245 ; Apr. 18, pp. 263–265). The author considers the factors affecting the magnitude of rolling loads. The effects of the surface condition of the rolls, the initial thickness of the metal, the influence of the roll diameter, the resistance to homogeneous deformation and the distribution of pressure on the roll face are discussed.—R. E.

Composition Bearings. W. A. Rankin. (Iron and Steel Engineer, 1947, vol. 24, Feb., pp. 81–82). A brief account of the applications of composition bearings in steelworks, other than roll-neck bearings is given.—M. A. V.

Steel Mill Production Scheduling. D. I. Brown. (Iron Age, 1947, vol. 159, Jan. 30, pp. 60–61). The planning of production in a steel mill to ensure maximum utilization of its capacity compatible with meeting customers' specifications is discussed and illustrated by a chart showing the schedule for a bar mill.—C. O.

The Art of Rolling Rounds. C. P. Hammond. (Iron and Steel Engineer, 1947, vol. 24, Jan., pp. 53–64). The different methods used in producing steel rounds are outlined. Details of American practice and equipment are described and illustrated.—C. O.

Developments in the Hot Rolling of Steel Sections and Bars in Germany. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1182 : H.M. Stationery Office).—R. A. R.

A New Precision Hot Rolling Mill. (Iron and Coal Trades Review, 1947, vol. 154, Mar. 28, pp. 521–526). A 14-in. two-high four-stand merchant mill for the hot rolling of a variety of steel sections, recently installed at the works of the Sheffield Forge and Rolling Mills Co., Ltd., is described. The mill incorporates certain special features in design, including the Tanway system of centralized grease lubrication of the roll-neck bearings, an arrangement for the fine adjustment of the bottom rolls, and a water channel to facilitate scale removal.—J. R.

Sheet Steel. J. H. Mort. (Iron and Steel, 1947, vol. 20, Jan., pp. 9–11). The bases of the three sheet gauges, the Birmingham, the Imperial Standard Wire, and the United States Standard, which are in common use in Great Britain are briefly explained. A nomogram and formulæ for the conversion of gauge numbers from one system to another are presented.—C. O.

Small Precision Cold Strip Mill. (Iron Age, 1947, vol. 159, Jan. 16, pp. 49–50). A short description of a small self-contained Sendzimir cold-strip mill is given. The mill is designed for the production of thin strip and foil, with an accuracy of ±0·0001 in. The backing-up rolls are of unconventional type; the pressure lubricating system also serves for cooling the rolls and the strip; and the whole equipment is housed in a fabricated steel mounting which requires no foundations.—C. O.

Cold Strip Reduced in One Pass at 4000 Feet per Minute. (Steel, 1947, vol. 120, Jan. 20, p. 80). A short description is given of a 56-in. 5-stand, 4-high cold-reduction mill. Sheet for tinplate can be produced at the rate of nearly 60 ton/hr. in one pass from strip 0·10–0·125 in. in thickness.—C. O.

Constant-Tension Reel Drives. E. S. Murrah. (Blast Furnace and Steel Plant, 1947, vol. 35, Feb., pp. 205–214). Reel drives for various types of strip mills are discussed, and formulæ are given for the calculation of appropriate data.—J. R.

Rolling-Mill Research. H. Ford. (Iron and Coal Trades Review, 1947, vol. 154, Jan. 24, pp. 171–178). A description is given of the experimental cold-rolling mill in the Metallurgical Department of the University of Sheffield, together with a short summary of the research work now being performed with it.—C. O.

Improved Production of Seamless Conical Tubes. (Machinery, 1947, vol. 70, Jan. 23, pp. 119–120). A short account is given of the production of seamless conical tubes by rolling in two stages. In the first, an internal mandrel and outer roll-discs are used to form a tube having sectional reductions, or shoulders, at intervals along its length. The second stage consists of pulling this stepped tube between two rollers having the contours of the finished tube. The shoulders are smoothed out during the passage of the tube through the rolls.—C. O.

Developments in the German Steel Tube Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 619: H.M. Stationery Office).—R. A. R.

Tension Sizing of Small Diameter Seamless Pipe and Tubing. S. Findlater. (Iron and Steel Engineer, 1947, vol. 24, Feb., pp. 87–97). This paper was prepared from data obtained by the Stretch-Reducing Mill Committee consisting of representatives of several tube-rolling companies in the United States. The difficulties encountered in designing high-speed mills for reducing the tube diameter without at the same time thickening the wall are discussed, and details are given of a 16-stand mill, with the stands very close together, in which the wall thickness is reduced by adjusting the stand speeds to put the tube in tension between the stands. Some off-gauge tubing has to be discarded from each end of the finished length, and means of reducing this wastage to a minimum are considered.—R. A. R.

Spot Conversion for Adjustable Speed Drivers. W. R. Hough and R. A. Geuder. (Iron and Steel Engineer, 1947, vol. 24, Feb., pp. 65–71). The advantages of having transportable units for the conversion of alternating to direct current and of placing them close to the motor for which variable speed control is required are explained. Units of this kind and their application to mill motors are described.—R. A. R.

Adjustable Voltage Drives Help Speed Auxiliary Equipment. G. A. Kaufman. (Iron and Steel Engineer, 1947, vol. 24, Feb., pp. 72–74). Descriptions are given of alternating to direct current conversion installations at two temper mills and the electrolytic cleaning line of the Jones and Laughlin Steel Corporation.—R. A. R.

Power Plant Engineering in 1946. (Boiler House Review, 1947, vol. 62, Feb., pp. 60–65). A summary is given of the activities of the British Thomson-Houston Co., Ltd., the English Electric Company, and C. A. Parsons and Co., Ltd., during the year 1946 in the production of turbo-alternators, compressors and rolling-mill drives.—R. A. R.

MACHINERY FOR IRON AND STEEL PLANT

Boiler Plant. (Iron and Steel, 1947, vol. 20, Apr., p. 132). Various types of steelworks boiler-plant installations are discussed.—J. R.

Plugging Relays Minimize Motor Reversing Time. R. B. Immel. (Steel, 1947, vol. 120, Apr. 7, pp. 106–110, 142–154). A direct-current motor may be reversed quickly by "plugging," *i.e.*, reversing the polarity of the voltage applied to the armature while it is rotating at full speed. The construction and operation of magnetically operated plugging relays are described in detail, and the sequence of operations illustrated diagrammatically. A suggested maintenance schedule is given.—M. A. V.

Amplidyne Regulating Systems. B. Adkins. (Institution of Electrical Engineers: Convention on Automatic Regulators and Servo Mechanisms, May 19–22, 1947). Owing to the fact that the field input of the amplidyne is much smaller than that of a normal generator, the amplidyne can be used as an automatic regulator for a wide variety of industrial equipment. The factors governing the accuracy, stability, and speed of response are discussed in relation to the whole system and to each component, as well as the effect of additional apparatus such as anti-hunt transformers and ballast regulators.—J. R.

Electric Control for Metalworking Machines. J. Van Voast. (Machinist, 1947, vol. 90, Apr. 26, pp. 2157–2172). A review is given of modern electrical circuits and controls for metalworking machines and gear, such as switches, relays, transformers, and rectifiers. Adjustable- and variable-speed drives and devices are also explained.—R. L. B.

Handling Materials for Steelmaking. C. M. Parker. (Iron and Steel Engineer, 1947, vol. 24, Mar., pp. 79–80). Statistics are given regarding the handling of iron and steelworks raw materials and products, and some of the necessary operations are outlined.—J. R.

Straightening Machinery. E. L. Tinley. (British Engineering Export Journal, 1947, vol. 29, May, pp. 1427–1437). A number of new problems have arisen in the straightening of metals, owing to the increased use of high-tensile alloys. The author surveys the forms and varieties of materials to be straightened and gives an illustrated description of the types of British machines designed to meet each requirement.—R. E.

MACHINING AND MACHINABILITY

How to Measure Machinability in the Shop. G. Schlesinger. (Machinist, 1947, vol. 90, Apr. 5, pp. 2041–2052). Methods and apparatus used in the practical determination of machinability are described and discussed.—C. O.

Good and Bad Structures in Machining Steel. N. E. Woldman. (Materials and Methods, 1947, vol. 25, Feb., pp. 80–86). Examples are given of the way in which microstructure affects the machinability of various types of steels.—C. O.

Machining Troubles Decline when the Metallurgist Sits In. N. E. Woldman and R. C. Gibbons. (Machinist, 1947, vol. 90, Mar. 29, pp. 2002–2006). Departmental co-operation in solving machining problems is discussed

and the aid which might be given by a metallurgist in solving some of the problems is stressed. Factors affecting machinability are tabulated. Fourteen cases are detailed whereby by means of examination of the microstructure and/or the hardness of the component, it was possible to specify a heat-treatment or other treatment and solve the problem. Improvements may also be suggested by metallurgical inspection where no machining problems exist.—R. L. B.

Giant Gear Generator Cuts Rolling Mill Pinions. (Iron Age, 1947, vol. 159, Mar. 6, p. 71). A description is given of a large Canadian gear-cutting machine designed to cut 30° herringbone gears up to 20 ft. in dia., and a face width of 66 in. It was recently used to make pinions for a 44-in. blooming mill.—R. A. R.

Tooling for Fabrication of Stainless Steel. J. C. Whitesell. (American Society of Tool Engineers, 1947, vol. 33, Feb., pp. 85–89, 112). The machines and tools used in fabricating stainless steel to make rolling stock and automobile trailer bodies at a plant in Philadelphia are described.—R. A. R.

Tool Steel Tubing. E. L. Cady. (Materials and Methods, 1947, vol. 25, Feb., pp. 87–89). The advantages of using tubes instead of solid bars in the manufacture of tool-steel components are enumerated.—C. O.

Practical Aspects of Surface Finish Measurement Instrumentation. J. A. Broadston. (Iron Age, 1947, vol. 159, Mar. 20, pp. 51–55). The advantages and limitations of different methods of measuring surface finish are discussed.—R. A. R.

Optimum Surface Finish with Sintered Carbide Tools. R. Gottschald. (Dresden Technical High School, Doctorate Thesis, 1942: Industrial Diamond Review, 1947, vol. 7, Apr., p. 122). The working conditions to be observed to obtain the most favourable surface finish when turning steel are presented.—R. E.

The Purpose and Aims of Diamond Technology. P. Grodzinski. (Industrial Diamond Association, Industrial Diamond Review, 1947, vol. 7, Apr., pp. 97–101). The applications of diamonds for industrial purposes are reviewed, and their use for grinding hardened steel components and for turning cast iron is suggested. —R. E.

POWDER METALLURGY

Symposium on Powder Metallurgy. (Iron and Steel Institute, 1947, Special Report No. 38). The Symposium on Powder Metallurgy was held on 18th and 19th June, 1947. Twenty-eight papers were presented and these were grouped into the following Sections: *A*. Introductory; *B*. Preparation, Properties, and Testing of Metal Powders; *C*. Magnetic Powders and Products; *D*. Hard-Metal Carbides; *E*. Porous Metal Components; and *F*. The Manufacture and Properties of Sintered Components. (Abstracts of the papers are given below). —R. A. R.

Powder Metallurgy in Great Britain. W. D. Jones. (*Ibid.*, pp. 1–2). A brief history of the development of powder metallurgy in Great Britain is presented.—R. A. R.

Production of Iron Powder by Electrodeposition. G. E. Gardam. (*Ibid.*, pp. 3–7). Experiments are described on the production of iron powder on a pilot-plant scale by electrolysis of 10% ferrous ammonium sulphate solution at 35° C., a *p*H of 2·5, and at 200 amp./sq. ft., half the current being fed through iron anodes and half through lead anodes in porous pots. The resulting furry deposit was scraped off the cathode at two-hourly intervals. The collected sludge was washed first with sulphuric acid and then with citric acid. The surrounding liquid was made ammoniacal and the powder washed, drained, and then rapidly dried under reduced pressure or in hydrogen. In this way a dendritic powder with an oxygen content of about 1% was obtained, but the hardness of the particles caused poor compacting properties. Annealing of the powder in hydrogen at not less than 600° C., and preferably at 700° C., for 1 hr., considerably improved the properties of the compact. A very tentative estimate of the costs of manufacture at the rate of 1 ton per week shows that the powder must be relatively expensive (1*s*. to 1*s*. 4*d*. per lb.).

Preliminary experiments on two other electrolytic methods of iron-powder production, *viz.*, electrodeposition and grinding of brittle flake iron and electrolytic reduction of ferrous hydroxide, are described briefly.

Production of Ferrous and Non-Ferrous Powders. G. L. Miller. (*Ibid.*, pp. 8–14). The processes used for the production of metal powders are classified in eleven groups. The applications of each method and the characteristics of the powder produced by it are briefly discussed, and the methods of production and properties of powders of the common industrial metals are tabulated.

Some Properties of Engineering Iron Powders. C. J. Leadbeater, L. Northcott, and F. Hargreaves. (*Ibid.*, pp. 15–36). The properties of 28 commercial iron powders, together with those of compacts prepared from them by a simple pressing and sintering technique, have been determined. The majority of the powders were prepared by either the oxide-reduction or electrolytic methods, but individual samples of the carbonyl, abrasion, and chloride-reduction methods were included.

At the outset of the investigation it became necessary to standardize or to develop methods of testing; these are described in Part I. The techniques for determining the particle, apparent, and tap densities of the powders, and the densities of the sintered compacts have been examined. The tap densities were found to vary with the method of tapping or vibration. The flow behaviour has been assessed by means of a coefficient determined by using cones with different orifices and weights of the powder sample; the effect of a cone stem on the rate of flow has been demonstrated. Modification of the air-permeability method for the determination of specific surface has been found necessary for coarse powders. Surface texture, particle size, shape factor, and crystal structure have been studied by micro-examination, and the oxygen, hydrogen, and nitrogen contents have been determined.

In Part II of the paper are described the properties of commercial powders, and the following ranges were found: Shape factor, 1·06–1·76; particle density, 7·26–7·89 g./c.c.; apparent density, 0·97–3·40 g./c.c.; tap density, 1·09–4·29 g./c.c.; flow coefficient, 1·24–6·4; median size, 6–114 μ; specific surface, 265–5161 sq. cm./g.; density after pressing at 30 tons/sq. in., 4·54–6·32 g./c.c.; compression ratio, 1·34–5·31; iron content (by difference), 96·70–99·64%; oxygen content, 0·10–2·09%.

The electrolytic iron powders are, in general, purer, and softer in the annealed condition, and have slightly greater compressibility than the oxide-reduced type, although both types show wide variation in properties.

The properties of sintered compacts are described in Part III. The compacts were prepared by pressing at 30 tons/sq. in. and sintering in hydrogen for 1 hr. at 1050° C. The properties determined extended over the following ranges: Tensile strength, 4·09–20·07

tons/sq. in.; yield point, 2·0–13·1 tons/sq. in.; elongation, 0–8·3%; diamond pyramid hardness, 22·5–113; density, 4·60–7·05 g./c.c.; volume shrinkage, — 1·56 to + 27·0%.

Electrolytic iron powders yield compacts having, on the average, slightly lower tensile strength and higher elongation than the oxide-reduced powders.

The results are considered in Part IV and additional data are adduced. A large number of simple correlation coefficients have been computed for the properties considered. It is clear that many factors contribute to the behaviour of a powder when it is pressed and sintered, and the properties of the compact are not dependent solely upon any one property of the powder. Further tests show that among the more important requirements for high tensile strength are small particle size and freedom of the surface of the particles from oxidation.

In an appendix F. M. Lea describes how the specific surface of iron powders is determined by a modification of the air-permeability method.

Flake Metal Powders—Their Application, Manufacture, and Testing Methods. H. Meyersberg. (*Ibid.*, pp. 37–46). The physical properties of flake and granular metal powders are compared. The production of flake powders of aluminium, copper, and bronze is concentrated mainly in America, Germany, and Great Britain. The output is considerable, the powders finding applications in the paint industry, because of their "covering" and "leafing" powers and lustre, in making lightweight concrete, and in pyrotechnics. Two methods of manufacture are in common use, the stamp and the modified ball mill, both of which are described in detail. In the stamping process there is grave risk of explosion of the fine dusts formed, especially with aluminium. This is obviated in the ball mill by using an inert atmosphere. A short account is given of the methods used in testing flake powders.

The Nature, Properties, and Applications of Carbonyl-Iron Powder. L. B. Pfeil. (*Ibid.*, pp. 47–51). The history of the development of carbonyl-iron powder is traced. It is shown that iron powder made by the carbonyl process possesses outstanding electromagnetic properties. These properties are associated with the spherical form, fine particle size, and structure of the powder. Production conditions are briefly described and tentative explanations of the cause of the special form and properties of the powder are offered. Reference is made to powder-metallurgy applications based on the high purity of the powder.

Comparison of Magnetic Powder Cores for High and Low Frequencies. G. R. Polgreen. (*Ibid.*, pp. 52–58). There are now a number of different ferromagnetic materials available for use in the electrical industry and the frequency range extends from low-power frequencies to frequencies of thousands of megacycles. For a large part of this range a variety of different sizes and shapes of powder cores have been developed and this paper gives a comparison of the properties of these various cores and of the materials from which they may be constructed.

Nickel-Iron Alloy Dust Cores. S. E. Buckley. (*Ibid.*, pp. 59–63). The development of dust cores to meet the increasing demand for use in telecommunications equipment is outlined. Requirements for such uses are defined, a high and constant permeability and low losses in the core being the most important. Amongst the materials for dust cores described are electrolytic iron, Permalloy (nickel–iron), and molybdenum–Permalloy.

The constancy of permeability and its influence on design, the question of calculating the dust-core permeability from inherent properties of the metal, and core losses are discussed; some figures are given illustrating the result of reducing core-loss coefficients over the course of dust-core development.

The effective resistances at audio frequencies of dust-cored coils of various materials are compared.

High-Magnetic-Permeability Powder-Iron Components. D. A. Oliver. (*Ibid.*, pp. 63–66). The commercial applications of magnetic iron powders are discussed and a summary is given of the desirable characteristics. In general the magnetic requirements can be said to be equivalent to those of a good quality fully annealed Armco iron, but with higher electrical resistivity and easier machinability. Some of the results of investigations now being carried out on grading, moulding pressure, sintering temperature, and other variables are presented.

The Production of Sintered Permanent Magnets. S. J. Garvin. (*Ibid.*, pp. 67–72). The stages in the production of sintered permanent magnets of iron–nickel–aluminium alloys are described. The difficulties normally associated with the development of a sintering technique are increased with these alloys because of the presence of aluminium, which readily becomes coated with a stable oxide, thus obstructing the diffusion reactions necessary for bonding. Very good and consistent results have been achieved by using binary alloys of aluminium with iron or cobalt in the preparation of powders, and by taking extreme precautions against oxidation during pressing and sintering.

The Preparation of Carbides. L. D. Brownlea, G. A. Geach, and T. Raine. (*Ibid.*, pp. 73–78). Methods used for the preparation of the carbides and double carbides of tungsten, titanium, and tantalum are described, and details are given of typical commercial practice in the manufacture of powders for cemented carbides.

The Manipulation and Sintering of Hard-Metals. H. Burden. (*Ibid.*, pp. 78–83). The main stages in the production of a consistent high-quality hard-metal from prepared powders to the sintered product are described. These stages are (*a*) pressing, (*b*) presintering, (*c*) shaping, and (*d*) sintering. Two main groups of powders are considered: The tungsten-carbide/cobalt group and the titanium-carbide/tungsten-carbide/cobalt group. Care in manufacture and choice of equipment are shown to have as important an effect on the properties of the finished material as have considerable changes in the contents of the major elements.

The Physical Metallurgy of Sintered Carbides. E. J. Sandford and E. M. Trent. (*Ibid.*, pp. 84–91). The physical and chemical changes in cemented carbides are discussed in relation to the sintering process, the course of which has been followed by measurement of the contraction and by microscopical examination. Sintering commences before a liquid phase appears, but is not complete until some time after. The distribution, size, and shape of the carbide grains are determined by the sintering process and the constitution of the alloy system, and the grain-size of the cobalt-rich phase is shown to be considerably greater than that of the carbide. The appearance of other phases in alloys of tungsten carbide and cobalt is discussed in relation to the carbon content, and present knowledge of the tungsten–carbon–cobalt equilibrium system is outlined. By comparing the theoretical and actual densities of cemented carbides, the porosity is shown to be very small. A brief

description is given of the more important physical properties, and the effect of additions of titanium and tantalum carbides is discussed.

The German Hard-Metal Industry. G. J. Trapp, B. E. Berry, H. Burden, and T. Raine. (*Ibid.*, pp. 92–98). Developments in the techniques of preparing and processing materials in the manufacture of hard-metals in Germany are described. The results of German researches into the structure and physical properties of hard-metals and their constituents are summarized.

The Structure of Porous Bronze Bearings. A. Carter and A. G. Metcalfe. (*Ibid.*, pp. 99–105). A brief description is given of the usual method of manufacture of porous bronze bearings and this is followed by an examination of three British commercial types of bearing. An attempt is made to correlate the structure of these bearings, determined by X-ray diffraction methods, with their other properties. In order to obtain more complete information, some experimental sinterings were carried out on copper–tin–graphite alloys, and the results obtained by various combinations of compacting pressure and sintering times and temperatures were compared with the properties of the bearings examined. The peritectic reaction at 798° C. between the α solid solution and the liquid was found to be of prime importance in the usual sintering cycles, giving rise to a sharp difference in structure and strength of the bearings. Hence it was possible to conclude that the one manufacturer uses temperatures in excess of 800° C., whereas the other bearings had been sintered below 800° C.

Highly Porous Metal Compacts, with Special Reference to Filters. C. E. Sinclair. (*Ibid.*, pp. 105–109). An account is presented of the characteristics of highly porous compacts suitable for use as filters. To obtain the desired control over filtering efficiency, it is necessary to use powders composed of graded spherical particles and examples are given of the flow and pressure-drop relationships on porous filters produced from such powders, together with micrographs of the pore size and shape. Owing to the high porosity, the mechanical properties are low, but the compacts are ductile and have a shock resistance far higher than that of ceramic filters. The paper concludes with notes on typical applications and service results.

Aircraft Liquid De-Icing Equipment. T. K. S. (Aircraft De-Icing), Ltd. (*Ibid.*, pp. 110–112). Conditions for ice formation on aircraft and details of early de-icing systems are reviewed. The urgent need in 1940 for a really satisfactory method of de-icing led to the development of the liquid de-icing system incorporating a porous-metal distributor with a sintered copper–nickel–tin compact as the porous medium. The construction and operation of this system are described in detail, and some notes on practical applications show that it is possible to remove thicknesses of at least $2\frac{1}{2}$ in. of ice.

The Properties of Certain Iron Powder Compacts. J. P. Burr and W. Clarke. (*Ibid.*, pp. 113–116). The effect of length on the density of electrolytic-iron powders compacted under various pressures and the effect of the addition of 1% of stearin on the tensile properties of sintered electrolytic-iron powder compacts have been determined experimentally. Values for the probable pressure losses at the centres of compacts have been calculated.

Iron-Carbon Alloys by Powder Metallurgy. J. A. Judd. (*Ibid.*, pp. 117–122). The majority of ferrous structural components at present in commercial production by the powder-metallurgy process are of low density and ferritic structure—factors which have an adverse influence on physical properties and therefore restrict the applicability of this technique. (Reference to both iron–copper alloys and high-density pure-iron parts is excluded.) The obvious methods of overcoming this disadvantage, *viz.*, either by increasing the density or by producing an essentially pearlitic material, are discussed. The production of higher densities is governed both by fundamental and by commercial considerations, the latter limiting the pressures and sintering temperatures to 50 tons/sq. in. and 1150° C. maximum.

The three main methods for producing sintered steels are discussed ; the advantage and limitations in respect of ease of compaction, ease of sintering, decarburization, and die wear being enumerated. It is concluded that for the higher-carbon alloys (hypereutectoid and graphitic steels) there is some advantage in the use of mixtures of iron powder with iron carbide and graphite powder, since the iron carbide liquates at sintering temperature, thereby strengthening the bond and improving physical properties. This method may also be used for the incorporation of alloying elements which are normally diffused during sintering only with great difficulty. Some results obtained by this technique, during the course of research work on aircraft piston-ring materials, are given, and it is shown that whereas elasticity modulus is almost a straight-line function of density, ultimate strength rises sharply in the higher-density range.

Pressing, Sintering, Heat-Treatment, and Properties of Iron–Graphite Powder Mixtures. R. Chadwick and E. R. Broadfield. (*Ibid.*, pp. 123–141). Investigations on the pressing, sintering, and heat-treatment of various grades of iron powders, with graphite additions, are described. Results are presented for three main types : (1) Electrolytic powder, (2) a charcoal-reduced Swedish powder, and (3) a German powder made by the Degussa process.

Although the powders varied considerably in purity and were from a variety of sources, they did not differ very much in their general properties, provided that they were annealed and fully reduced before use.

Graphite additions enabled rapid and effective diffusion of carbon to take place at temperatures of 1000° C. or above, and pearlitic structures with either ferrite or cementite, according to the percentage of carbon, are formed.

All the powders were found to be capable of forming typical steels and under appropriate conditions were suitable for heat-treatment.

Sintered Iron–Copper Compacts. L. Northcott and C. J. Leadbeater. (*Ibid.*, pp. 142–150). The properties of sintered compacts of iron–copper alloys have been studied. Substantial improvement in tensile strength and hardness is observed with up to 25% of copper, and the advantage of sintering at a temperature above the melting point of the copper is reflected in the microstructure. In general, improvement is greatest with copper of small particle size, but this may not be true with coarse particle irons. The beneficial effect of copper in increasing the scuffing load has been shown. The impregnation of pressed iron compacts with molten copper results in sintered compacts of high density. There is a close relationship between tensile strength and equivalent density, irrespective of the method of manufacture of the compact ; for constant porosity the maximum strength was obtained with about 10% of copper.

Observations on the Pressing, Sintering, and Properties of Iron-Copper Powder Mixtures. R. Chadwick, E. R. Broadfield, and S. F. Pugh. (*Ibid.*, pp. 151–157). A study has been made of the effects of variations in particle size, pressure of compaction, and temperature of sintering on the properties of sintered compacts of iron–copper powder mixtures containing up to 35% of copper. Copper and iron form no brittle phases and it is possible to obtain strong sintered compacts over a wide range of compositions, the optimum strength and ductility being obtained with a 75/25 iron–copper mixture, at temperatures high enough to melt the copper-rich phase powders finer than 240-mesh B.S.S. The compressibility of mixtures is important in determining shrinkage on sintering and mechanical properties.

Powder-Metallurgy Bearing Materials. W. H. Tait. (*Ibid.*, pp. 157–161). The unique qualities of powder-metallurgy methods which are utilized in the production of bearings and thrust washers are discussed. An outline is given of the materials and methods used in Great Britain for obtaining porous, self-lubricating structures and non-porous structures which are difficult or impossible to manufacture by means other than powder metallurgy. Mention is made of recent developments and of future prospects in these fields. Information on the influence of structure on the behaviour of copper–lead bearings and the influence of elastic modulus on the properties of bearing materials is contained in two appendices.

The Pressing and Sintering of Copper Powders. M. Cook and S. F. Pugh. (*Ibid.*, pp. 162–173). Copper powders made by a variety of methods have been studied, the behaviour in pressing and sintering being related to characteristic particle shape and to particle-size grading. The physical characteristics of the powders, compressibility, dimensional changes resulting from sintering, and tensile strength and ductility of sintered products, have been examined, and an explanation is afforded for their behaviour.

The Production of Some Non-Ferrous Engineering Components by Powder Metallurgy. J. W. Lennox. (*Ibid.*, pp. 174–184). An investigation has been made into the optimum conditions of pressing and sintering for the production of the best physical properties in brass and bronze engineering components. For a 70/30 brass it is preferred to use a fully alloyed powder cold pressed at 30–35 tons/sq. in., sintered at 900° C., and re-pressed at 30–35 tons/sq. in., giving a compact with a tensile strength of 15 tons/sq. in., an elongation of 14%, and a density of 7·69 g./c.c. For a 90/10 bronze it is preferred to use extra fine powders pressed at 30 tons/sq. in., sintered at 800° C., re-pressed at 30 tons/sq. in., and re-sintered at 800° C., giving a compact with a tensile strength of 12 tons/sq. in., an elongation of 10%, a density of 7·9 g./c.c., and a Brinell hardness number of 61. The practical significance of these results is discussed and some notes are given on commercial production of brass and bronze components.

Aluminium Components. R. L. Bickerdike. (*Ibid.*, pp. 185–191). After dealing briefly with methods of obtaining oxide-free aluminium powders, some experiments on hot and cold-pressing and sintering of copper–aluminium powders are described. The pressure and the sintering temperature used were found to have a critical effect on the properties of sintered compacts. Test-pieces in the form of discs $1\frac{1}{8}$ in. in dia. and $\frac{1}{4}$ in. thick were used and results are presented of microscopical examination, density and hardness measurements, and tensile testing.

Notes on German Developments in Non-Carbide Powder Metallurgy (1939-1945). C. J. Leadbeater. (*Ibid.*, pp. 191–202). A brief survey is made of the developments in the production of metal powders, the manufacture of sintered components, the types of equipment used in pressing and sintering, and the researches undertaken to study the mechanism of sintering.

Several significant developments occurred in powder production. The flake-powder industry was reorganized and re-equipped for producing pyrophoric aluminium (13,000 tons/year), whilst the production of iron powder exceeded 3000 tons/month. Disc- and air-atomization methods developed for iron powder provided satisfactory grades of product and increased rates of output and showed promise of replacing the mechanical Hametag process, the disadvantages of which were low rate of output and high capital and maintenance costs. Molybdenum powder of greater purity was obtained by distilling the oxide before reduction.

Only a few types of components, such as driving-bands, bearings, and filaments, were made on a commercial basis although many, principally of dense steel, had reached the development stage.

An ingenious arrangement of sprung sub-multiple punches had been devised to attain a uniform compression-ratio in components of complicated shape. Hydraulic and mechanical presses were in general use, with multiple die-stations for pressing small bearings and bullet-cores.

German Sintered Iron Driving Bands. W. Ivory. (*Ibid.*, pp. 203–208). An outline is given of the size and organization of the German wartime production of iron powder, and the development, manufacture, and testing of sintered iron driving bands is described in detail.

The Moment of Active Deformation. H. L. Strauss, jun. (Metal Progress, 1947, vol. 51, Feb., pp. 254–255). Some tests in powder metallurgy in which the pressing and the heating take place simultaneously are described. It was noted that there was a period when the time and temperature were such that the material suddenly assumed a degree of plasticity far greater than that obtainable when the sintering followed the cold-pressing. This period is called the "moment of active deformation." The temperature at this moment was found to be approximately one-third of the melting point of the metal (in Fahrenheit), and the pressure required was in several cases about one-sixteenth of that required for cold-pressing.—R. A. R.

The Calculation of the Diffusion Coefficient in Mixtures of Powdered Substances. S. Hertzrücken and M. Feingold. (Iron and Steel Institute, 1947, Translation Series No. 308). This is an English translation of a paper which appeared in Journal of Technical Physics, U.S.S.R., 1940, vol. 10, No. 7, pp. 574—577. A method for the calculation of the diffusion coefficient in mixtures of powdered metals sintered at various temperatures is developed.—D. R. S.

Powder Metallurgy. J. W. Lennox. (Machinery, 1947, vol. 70, Apr. 3, pp. 337–344). A short account is given of the sequence of operations in the production of parts by the methods of powder metallurgy.—C. O.

Iron Cored D.F. Loops and Manufacture of Iron Dust. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1203: H.M. Stationery Office). German methods of preparing iron dust and making iron-cored direction-finding loops for aeroplanes are described.—R. A. R.

Plastic Deformation in Metal-Powder Compacts. R. Kamm, M. Steinberg, and J. Wulff. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2133 : Metals Technology, 1947, vol. 14, Feb.). A description is given of the use of deformable lead grids and radiography for determining the density distribution in powder-metal compacts. The densest part of a compact pressed from one side only was found to be at the outer circumference at the top (*i.e.*, near the movable plunger) and the least dense part at the bottom. To a first approximation there is no lateral movement of powder in a cylindrical die. Friction on the die walls is a factor controlling the irregularity of density distribution. Side-wall lubrication appears to be of greater importance than inter-particle lubrication. —C. O.

Preparation of Iron Powder Compacts and Powders for Microscopic Examination. H. M. Jamison and E. S. Byron. (Metal Progress, 1947, vol. 51, Mar., pp. 437–440).—C. O.

Iron Powders. (Iron and Steel, 1947, vol. 20, Mar., p. 108). Owing to the availability of Swedish sponge-iron powder and the recent advances made in its production, many components previously fabricated by machining can now be made more economically by means of powder metallurgy.—J. R.

PROPERTIES AND TESTS

Is There a Relation between Metallurgy, Engineering and Materials Specifications ? F. G. Tatnall. (Society of Automotive Engineers : Steel Processing, 1947, vol. 33, Feb., pp. 92–95). **Metallurgy, Engineering and Specs.** F. G. Tatnall. (S.A.E. Journal, 1947, vol. 55, Apr., pp. 55–57). The application of various methods of testing and their value in estimating the suitability of materials for certain structures are discussed from the point of view of drawing up specifications.—R. A. R.

New Knowledge Relating to Strength Investigations. E. Siebel and M. Pfender. (Technik, 1947, vol. 2, Mar., pp. 117–121). The nature of the test data required for the design of structures to withstand unevenly distributed stresses is discussed, with several references to the literature.—R. A. R.

The Tensile Yield Strength of Certain Steels under Suddenly Applied Loads. F. V. Warnock and J. B. Brennan. (Institution of Mechanical Engineers, Apr., 1947, Preprint). Dynamic tensile yield stresses were determined for a mild steel, two plain carbon steels, two manganese steels, a heat-treated nickel–chromium–molybdenum steel, and two cast steels, using an impact machine of the falling-weight type. The following conclusions were reached : (1) Normalized mild steels and annealed cast steels exhibit an increase in yield stress under dynamic tensile loading ; (2) heat-treated alloy steels have substantially the same yield stress under static and dynamic tensile loading ; (3) the sensitivity of the yield stress to rate of loading decreases with increase in static yield stress ; (4) it may be possible to determine a practical value of dynamic yield strength from a static test ; and (5) the stress system in a specimen subject to rapidly acting stress becomes fundamentally different at very high rates of loading with a short specimen.—R. A. R.

The Initiation and Propagation of the Plastic Zone in a Tension Bar of Mild Steel Under Eccentric Loading. J. Miklowitz. (Journal of Applied Mechanics, 1947, vol. 14, Mar., pp. A-21–A-30). The results of several tensile tests on flat mild-steel bars under eccentric loading are presented. A theory is formulated to explain the formation of the wedge-shaped plastic zones which were formed. A comparison is made of the yielding under concentric and eccentric loading.—C. O.

The Initiation and Propagation of the Plastic Zone in a Tension Bar of Mild Steel as Influenced by the Speed of Stretching and Rigidity of Testing Machine. J. Miklowitz. (Journal of Applied Mechanics, 1947, vol. 14, Mar., pp. A-31–A-38). The results of several tests with round and flat bars of mild steel and iron, under the influence of variations in speed of stretching and testing-machine rigidity are presented. Attention is focused on the initiation of the plastic zone and the propagation of the boundaries of this zone along the length of the specimens. —C. O.

Length Changes in Metals under Torsional Overstrain. H. W. Swift. (Engineering, 1947, vol. 163, Apr. 4, pp. 253–257). Nadai's theory that stress-strain relationships could be derived graphically from the torque-twist curve was tested by comparing shear stress-strain curves obtained from solid bars by his construction with similar curves obtained from hollow specimens in which the stress distribution could be regarded as uniform. The results provide evidence that : (1) Under plastic strain (which is essentially shear strain) of a crystalline body, both sliding and rotation occur in the crystal grains, and the material cannot be regarded as fully isotropic after any measurable strain has occurred ; (2) the strain-hardening of crystal grains is directional in character, more particularly in metals having a face-centred cubic structure ; (3) full annealing is necessary to restore the isotropic properties of overstrained material ; (4) the effects of differential behaviour of crystal grains cannot be allowed for by the law of averages (the statistical result may be quite considerable on a macroscopic scale) ; and (5) it is unlikely that the axes of plastic strain in crystalline bodies will coincide with the axes of stress except under very simple conditions of symmetry, and still less likely, therefore, that Lode's hypothesis can be generally valid.—R. A. R.

Ingenious New Testing Machine. (Overseas Engineer, 1947, vol. 20, Apr.–May, p. 320). A short description is given of a newly designed 25-ton universal testing machine.—C. O.

The Influence of Size on the Brittle Strength of Steel. N. Davidenkov, E. Shevandin, and F. Wittmann. (Journal of Applied Mechanics, 1947, vol. 14, Mar., pp. A-63–A-67). The influence of size upon the impact strength of carbon steel is discussed. Static bend tests of notched specimens and the determination of the critical temperature of impact brittleness show that high velocity or stress gradients cannot account for the size effect. The statistical nature of the effect is clearly revealed by the results of static tension and bending tests on cylindrical specimens in liquid air, which give a good qualitative verification of Weibull's theory.—C. O.

Reproducibility of the Single-Blow Charpy Notched Bar Test. N. A. Kahn and E. A. Imbembo. (A.S.T.M. Bulletin, 1947, May, pp. 66–74). The results of Charpy impact tests on bars of the same stress-relieved, semi-killed low carbon steel, using keyhole-notch and V-notch specimens, carried out at seven laboratories are compared. The reproducibility of the results from the former was better than those from the latter.—R. A. R.

Stress Analysis. (British Engineering Export Journal, 1947, vol. 29, Apr., pp. 1281–1284, 1302). Equipment for the electronic measurement of strain and vibration is described and illustrated.—R. E.

Stress Analysis. (Metal Industry, 1947, vol. 70, May 30, pp. 399–400). Illustrated particulars are given of a polariscope designed by David Brown and Sons (Huddersfield) Ltd., for stress analysis of machinery components.—R. E.

Stress Analysis by Photo-Elastic Methods. C. Mylonas. (Mathematical and Physical Society of University College: Sheet Metal Industries, 1947, vol. 24, Apr., pp. 807–809). The theory of stress analysis by polarized light figures is explained and some practical examples of its use are illustrated.—R. A. R.

Stress Analysis by Polarised Light. (Engineer, 1947, vol. 183, May 23, pp. 454–455). A description is given of a "Polariscope" which was designed for the study of stress concentration in gear teeth and the determination of suitable tooth proportions.—R. A. R.

Relation of Mechanical Properties and Internal Stresses to Casting Design. R. A. Flinn. (Foundry, 1947, vol. 75, Apr., pp. 106–109, 267–270). The application of experimental stress analysis to casting design is discussed.—C. O.

Some Experiments on the Distribution of Deflection and Stress in Thin Flat Plates. H. D. Conway and V. C. Davies. (Sheet Metal Industries, 1946, vol. 23, Nov., pp. 2147–2151; Dec., pp. 2393–2398, 2400; 1947, vol. 24, Feb., pp. 355–363; May, pp. 993–999). An account is given of experimental work on a number of problems met with in structural design in the use of flat plates the edges of which are subjected to a negligibly small fixing moment; in particular, the case of circular plates loaded with a uniform pressure and supported at four points equidistant from the centre was investigated by determining the deflections and stresses analytically.—C. O.

Introduction to the Fatigue of Metals. H. H. Egginton. (Journal of the Birmingham Metallurgical Society, 1947, vol. 27, Mar., pp. 258–278). Definitions are given for fatigue, endurance or fatigue limit, and endurance ratio. An historic review is followed by details of the Wöhler methods of fatigue testing, and the alternative methods of expressing results. The effects of frequency, temperature, cold-working, and annealing, understressing, stress concentrations, and corrosion in endurance and fatigue testing are briefly discussed, together with the theory of fatigue propagation, and some formulæ are given for the calculation of endurance stresses.—R. L. B.

Twelfth Progress Report of the Joint Investigation of Failures in Railroad Rails in Service and Their Prevention. R. E. Cramer and R. S. Jensen. (Illinois University, 1946, Engineering Experiment Station, Reprint Series No. 35, pp. 3–16). Investigations of the causes of rail failures have been continued (*see* Journ. I. and S.I., 1946, No. II, p. 13A). Service tests on end-hardened rails, failures in control-cooled and Brunorized rails, and the control-cooling of 3%-chromium rails are reported.—R. A. R.

Fourth Progress Report of the Rolling-Load Tests of Joint Bars. N. J. Alleman. (Illinois University, 1946, Engineering Experiment Station, Reprint Series No. 35, pp. 17–29). The tests reported show that hot-sawing of rail ends distorts the fishing surface, and the condition of the rail end has an effect on the fatigue life of joint bars. Shell steel and high-manganese steel bars were satisfactory provided that the Brinell values were not too high.—M. A. V.

Fourth Progress Report of the Shelly Rail Studies at the University of Illinois. R. E. Cramer. (Illinois University, 1946, Engineering Experiment Station, Reprint Series No. 35, pp. 30–34). The physical properties of rail steels were determined, and laboratory rolling-load tests carried out.—M. A. V.

Fatigue Tests of Rail Webs. R. S. Jensen. (Illinois University, 1946, Engineering Experiment Station, Reprint Series No. 35, pp. 35–37).

A Preliminary Investigation of Corrugated Rails. R. E. Cramer. (Illinois University, 1946, Engineering Experiment Station, Reprint Series No. 35, pp. 38–40). Flame-tempering was found to be a promising means of removing corrugations, which were hard spots due, among other things, to wheel-slip.—M. A. V.

Carbide Instability of Carbon–Molybdenum Steel Piping. R. W. Emerson. (Welding Journal, 1947, vol. 26, Feb., pp. 104-s–114-s). An investigation of the complete failure of a carbon–molybdenum steel pipe adjacent to a weld revealed the failure to be the result of graphite segregation. The examination of a number of specimens taken from other welded joints in high-temperature steam pipes has shown that graphitization occurs in the base metal at the extremity of the heat-affected zone of the weld, and may be in either "chain" or "nodular" form. Relatively large quantities of aluminium for deoxidising are believed to have an adverse effect on the stability of the carbides; the temperature of post-heating or stress-relieving may be very important in determining whether segregated graphite will occur in a steel which has inherent carbide instability.—C. O.

The Production of Synchronous Superimposed Bending and Torsional Fatigue Stresses. O. Puchner. (Schweizer Archiv, 1946, vol. 12, Sept., pp. 289–293). The possibilities of adapting ordinary testing machines for the simultaneous application of bending and torsional fatigue stresses is discussed.—R. A. R.

Selecting Steels by Hardenability Bands. C. M. Parker. (Materials and Methods, 1947, vol. 25, Mar., pp. 68–72). The wide range of mechanical properties which may result, after heat-treatment and subsequent fabrication or machining, from slight variations within the maximum and minimum figures for chemical composition, has led to the development of a method of selection on the basis of hardenability. Tentative hardenability bands (determined by the Jominy end-quench method) for steels used during the war, has resulted in the manufacture of "H steels"—the steels of which the as-cast composition and subsequent treatment have been regulated according to the specified hardenability data. By this method of control, undesirable mechanical properties brought about by the percentages of all the alloying elements being too high or too low, may be eliminated. Five ways are given for designating hardenability, any one of which may be suitable.—R. L. B.

Hardenability in Relation to Steel and Cast Iron—Its Meaning and Measurement. A. Portevin. (Revue de Métallurgie: Iron and Coal Trades Review, 1947, vol. 154, Apr., 18, pp. 683–688; Apr. 25, pp. 719–724; May 2, pp. 769–773). The development of the concept of hardenability is traced from the 1914–1918 period to the more recent studies of Grossmann, Jominy, Janitzky, Davenport, and Bain, and the work carried out on the chilling power of cast iron is considered. The relation between the rate of cooling and the amount of combined or graphitic carbon is discussed, and a simple theory is advanced for the explanation of the process of malleablizing. Other features which influence graphitization are mentioned, and a section on the variety of test-pieces available for the determination of hardenability is included.—J. R.

The Effect of Surface Conditions in Hardness Measurements. P. Bastien and A. Popoff. (Revue de Métallurgie, 1945, vol. 42, Dec., pp. 373–388). The authors measured the hardness of a series of specimens of a mild steel and a high-speed steel, in the highly polished and roughly emery-papered conditions, by means of the Herbert pendulum test, the Vickers diamond-pyramid test and the "E.P." micro-hardness test, and evaluated the results statistically. Their conclusions are that hardness measurements can be either independent of the state of the surface, or that they are a direct function of the state of the surface, *e.g.*, in the pendulum test, where

the effect of surface treatment is revealed and where there is an inherent difference in the hardness value according to whether the pendulum oscillates perpendicular or parallel to the direction of rolling. The micro method should be used only on soft polished metal. Values on the Vickers scale are converted to the Herbert scale by the formula : $V = 9{\cdot}78\,H - 35{\cdot}34$.—R. A. H.

The Aging of High-Tensile Structural Steel. A. Fry and L. Kirschfeld. (Welding Journal, 1947, vol. 26, Mar., pp. 149-s–152-s). This is an abridged English translation of a paper which appeared in Zeitschrift des Vereines Deutscher Ingenieure, 1943, vol. 87, Mar. 6, pp. 123–127 (*see* Journ. I. and S.I., 1944, No. II, p. 162A).—R. A. R.

Recent Swedish Investigations on the Ageing of Steel. B. D. Enlund. (Iron and Steel Institute, 1947, Translation Series, No. 307). This is an English translation of a paper which appeared in Jernkontorets Annaler, 1946, vol. 130, No. 10, pp. 553–573. (*See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 312).—D. R. S.

Temper-Brittleness in Alloy Steel. (Engineer, 1947, vol. 183, Apr. 4, pp. 286–287). Recent papers on temper-brittleness in alloy steels are reviewed.—R. A. R.

Temper-Brittleness. R. H. Greaves. (Iron and Steel, 1947, vol. 20, May, pp. 175–178). Recent work carried out by French investigators upon the subject of temper-brittleness is reviewed and discussed.—J. R.

Reducing Metal Wear with Abrasion-Resisting Castings. J. S. Vanick. (American Ceramic Society Bulletin, 1947, vol. 26, Apr. 15, pp. 109–116). An investigation was conducted on steels and cast irons which possess special merit as wear-resisting materials, and laboratory studies on their physical properties and wear resistance are described. The resistance of the hardest chilled irons used in mining suggested the application of Ni-Hard to muller tyres, scrapers, knives, and augers. Machinable cast irons possessing wear-resisting structures used as-cast at a Brinell hardness number of 200 to 300 have been developed for forming dies for the metal industry as well as for the ceramic industry.—R. A. R.

Time-Dependent Phenomena in Iron-Bearing Materials under the Influence of Mechanical and Magnetic Forces. J. L. Snoek. (Schweizer Archiv, 1947, vol. 13, Jan., pp. 9–14). Bloch's theory of magnetization is explained and it is then applied to the study of two groups of phenomena relating to ferromagnetic after-effects, namely, long-time and short-time after-effects.—R. A. R.

Magnetoresistance and Domain Theory of Iron–Nickel Alloys. R. M. Bozorth. (Physical Review, 1946, vol. 70, Dec. 1 and 15, pp. 923–932). Measurements of the change of electrical resistivity with magnetization and with tension are reported for iron–nickel alloys containing 40–100% nickel. When the magnetostriction is negative (81–100% nickel), tension (σ) decreases resistivity and magnetic field (H) increases it. The ratio σ/H at which the resistivity is equal to that of the unmagnetized specimen is found to be the same as that predicted by the domain theory.—C. O.

"Spoiling" of Tungsten Steel. K. Hoselitz and M. McCaig. (Nature, 1947, vol. 159, May 24, p. 710). The intensities of magnetization of tungsten-steel specimens heated for various periods at 950° C. were measured. The results support the theory that the "spoiling" of tungsten steel, *i.e.*, the reduction of the coercive force after holding at 950–1000° C., is due to the formation of tungsten carbide and the consequently lower proportions of tungsten and carbon in solid solution.—D. R. S.

Soft Iron for Magnetic Cores. (British Intelligence Objectives Sub-Committee, 1947, Miscellaneous Report No. 10 : H.M. Stationery Office). A brief interrogation of an official of Röchling Buderus on the manufacture of soft iron magnet cores is reported. He stated that Swedish soft iron was the best material and that it was impossible to estimate the proportion of reducing materials in the original charge to give a product with neither surplus oxygen nor surplus reducing agent. The effect of silicon, titanium, and vanadium on the coercive force is briefly dealt with.—R. A. R.

Permanent Magnet Design. D. Hadfield. (Electrical Times, 1947, vol. 111, Mar. 20, pp. 290–294 ; Mar. 27, pp. 323–325 ; Apr. 3, pp. 357–359). A review is made of the permanent-magnetic materials commercially available, and numerous formulæ are given for the determination of the volume, length, and cross-sectional area for most types of magnets.—J. R.

Medium-Frequency Magnetization of Sheet Steel. R. Pohl. (Journal of the Institution of Electrical Engineers, 1947, vol. 94, Part II, Apr., pp. 118–123). The influence of hysteresis upon the eddy-current loss, the apparent flux, and the utilization factor in medium-frequency power circuits is discussed, and theoretical expressions for these are presented in a form convenient for laboratories and design offices.—J. R.

A Method for Predicting Failure of Metals. P. E. Cavanagh. (A.S.T.M. Bulletin, 1946, Dec., pp. 30–33). The possibility of using changes in high-frequency magnetic and eddy-current losses to predict failure in metals is discussed. The method of recording changes in total magnetic and core losses is described and examples of stress/core-loss curves are given.—C. O.

Magnetic Aids to Industry. H. E. Hutter. (Power and Works Engineering, 1947, vol. 42, May, pp. 131–132). Magnetostriction and other terms related to magnetism are explained and the principles of many magnetic instruments for testing and control purposes are briefly described.—R. A. R.

Magnetic Testing. R. L. Sanford. (National Bureau of Standards, 1946, Circular No. C.415). This circular gives general information regarding magnetic quantities, the magnetic characteristics of materials, the principles employed in magnetic testing apparatus, and a brief discussion of the theory and application of magnetic analysis.—R. A. R.

Magnetic Particle Inspection of Chromium-Plated Tools. M. H. Mueller and W. E. Yeast. (Metal Progress, 1947, vol. 51, Mar., pp. 420–425). The manner in which chromium plating tends to conceal defects from detection by magnaflux methods is illustrated. A visible "build-up" of magnetic particles can be obtained if a full-wave-rectified alternating current of 25,000 amp.-turns is maintained throughout the inspection.—C. O.

Recording Magnetic Detector Locates Flaws in Ferrous Metals. C. H. Hastings. (Product Engineering, 1947, vol. 18, Apr., pp. 110–112). An instrument for detecting flaws in ferrous materials by measuring the change in magnetic flux density in the region of defects is described and illustrated.—C. O.

Supersonic Waves Locate Die-Block Flaws. R. W. Snowdon. (Steel, 1947, vol. 120, Apr. 7, pp. 95, 136–137). A short account is given of the technique used in the routine examination of die-blocks by the Sperry supersonic reflectoscope.—C. O.

Low-Temperature Physics and the Theory of Metals. E. B. Mendoza. (Metal Treatment, 1947, vol. 14, Spring Issue, pp. 20–28). An account is given of some of the techniques of low-temperature physics, and some results of research of interest to metallurgists are discussed. A number of specific heat anomalies are described ; these include the loss of the magnetic properties of nickel where the parallel orientation of the atomic magnetic dipoles is upset above 635° C. The magnetic effect due to the presence of spinning electrons, research work in

progress on nuclear paramagnetism, and the superconductivity of certain metals are discussed.—R. A. R.

Tests of Instruments for the Determination, Indication, or Recording of the Specific Gravities of Gases. F. A. Smith, J. H. Eiseman, and E. C. Creitz. (United States National Bureau of Standards, 1947, Miscellaneous Publication M177).

Evaluating High Heat Properties of Steel. H. Dobkin. (Steel, 1947, vol. 120, Apr. 21, pp. 86–87, 120–124). Methods of measuring the properties of steels at high temperature, and their significance in relation to the applications of the steels are discussed.—R. A. R.

The Gas Turbine. Sir Claude Gibb and A. T. Bowden. (Journal of the Royal Society of Arts, 1947, vol. 95, Mar. 28, pp. 265–317). A short historical survey is given of the gradual development of the gas turbine, and some technical problems associated with industrial gas-turbine design and operation are considered. The requirements of metals for turbine construction are touched upon and some of the more important properties are evaluated. —R. E.

High Creep Strength Austenitic Gas Turbine Forgings. D. A. Oliver and G. T. Harris. (Institute of Marine Engineers: Engineer, 1947, vol. 183, May 30, pp. 468–469; June 6, pp. 502–503). **Creep-Resistant Forgings for Gas Turbines.** D. A. Oliver and G. T. Harris. (Iron and Coal Trades Review, 1947, vol. 154, Apr. 25, pp. 731–732). Some examples of the applications of high-alloy heat-resisting steels and "Nimonic 80" to gas turbines are cited, and compositions and data on their high-temperature characteristics are given. Particular reference is made to the complex niobium-bearing stainless steel "G.18B."—R. A. R.

The Development of the Creep-Resisting Types of Steel. A. J. Zuithoff. (Metalen, 1947, vol. 1, Apr., pp. 133–138). (In Dutch). The development of heat-resisting steels and high-alloy steels, especially during the last five years, is reviewed.—R. A. R.

Heat-Resisting Metals for Gas-Turbine Parts. H. C. Cross and W. F. Simmons. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June, pp. 3–51). This report shows the results of high-temperature tests on heat-resisting alloys carried out under National Defense Research Committee Project NRC-8 to study and evaluate new alloys. The materials studied ranged from modified 18%-chromium 8%-nickel steels to practically iron-free cobalt–chromium and cobalt–chromium–nickel alloys with additions singly or in combination of molybdenum, tungsten, columbium, tantalum, titanium, aluminium, boron, and nitrogen. Short-time tension tests were made on the precision-cast cobalt-base alloys at 538–871° C. Stress-rupture tests were made at 816°, 871°, and 1093° C. to determine the stresses for rupture in times varying from 100 to 1000 hr. Creep tests were made at 732°, 816°, and 871° C. to pick out the better alloys and to determine the stresses required to produce creep rates of 0·00001%/hr. The cast cobalt-base alloys show better stress-rupture and creep properties generally than the forged alloys, except for creep resistance at 732° C. Design curves based on both stress-rupture and creep data at 816° C., show that for low values of total deformation, some of the forged alloys are superior to the cast alloys.

High-Temperature Alloys Developed for Aircraft Turbo-Superchargers and Gas Turbines. J. W. Freeman, E. E. Reynolds and A. E. White. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June, pp. 52–79). In recognition of the advantages to be obtained through the use of the gas turbine in aircraft power plants, the National Advisory Committee for Aeronautics started to sponsor research work in November, 1941, to develop suitable heat-resistant alloys. This paper describes the alloys which have evolved from the phase of their work conducted under contracts at the University of Michigan. Owing to necessary restrictions under wartime conditions, the results have previously only been given limited circulation. The activities of the NACA in the field of heat-resistant alloys have been directed by a Special Sub-Committee on Metals for Turbosupercharger Wheels and Buckets and its successor the Sub-Committee on Heat-Resisting Alloys. Actually the investigation at the University represents parts of a co-operative effort to develop improved heat-resistant alloys in which the members of the sub-committee extensively utilized the facilities of their companies and organizations to extend the scope of the work.

Chromium-Base Alloys. R. M. Parke and F. B. Bens. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June, pp. 80–98). This paper describes an investigation of chromium-base alloys, a class of heat-resistant materials not well known. The investigation was supervised during its entirety—for 3½ years—by the War Metallurgy Committee of the National Defence Research Committee, through contract with Climax Molybdenum Co. It was part of a project entitled "Development of Heat-Resistant Metals for Gas-Turbine Parts." In particular, the heat-resistant metals being sought were for use as gas-turbine blades rotating in an oxidizing atmosphere at temperatures up to 870° C. During the final year of the investigation, the alloys were applied experimentally as erosion-resistant materials for ordnance uses under the supervision of Division One, NDRC.

Metallurgy of High-Temperature Alloys Used on Current Gas Turbine Designs. F. S. Badger, jun., and W. O. Sweeny, jun. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June, pp. 99–112). This paper outlines the development of the two original groups of alloys, one with a nickel base and the other a cobalt base, which were used, and covers their successful fabrication by forging and by precision casting to meet the wartime mass-production requirements. Metallurgical data not previously published are presented, as well as a discussion of the importance of certain mechanical properties as related to design. An indication of the probable benefits of the new and relatively untried high-temperature alloys, and an outline of what may be expected in the near future from alloys now in the development stages are included.

Alloys and Ceramic Materials for High-Temperature Service. H. C. Cross. (Symposium on Materials for Gas Turbines, American Society for Testing Materials, 1946, June, pp. 113–120). The author discusses a plan of research being carried out at Battelle Memorial Institute under contract with the Office of Research and Inventions, Navy Department. The materials now under test include the following: (*a*) Low-carbon alloy type N-155 (C 0·15%, Cr 20%, Ni 20%, Co 20%, Mo 3%, W 2%, and Cb 1%); (*b*) type S-590 (C 0·45%, Cr 20%, Ni 20%, Co 20%, W 4%, Mo 4%, Cb 4%); (*c*) type S-816 (C 0·40%, Cr 20%, Ni 20%, Co 45%, W 4%, Mo 4%, and Cb 4%); (*d*) Inconel-X (C 0·05%, Cr 14%, Ni 74%, Ti 2·3%, Al 0·7%, Cb 1·0%, and Fe 7%); (*e*) Refractaloy 26 (C 0·03%, Cr 18%, Ni 37%, Co 20%, Mo 3·1%, Ti 3%, and Al 0·25%; (*f*) S-816 and rolled Vitallium (C 0·25%, Cr 27%, Ni 3%, Co 62%, and Mo 5·5%). The effect of metal pouring temperature has been explored and damping capacity and tension-fatigue tests have been carried out. Further, an investigation of fundamental factors promoting high-temperature

stresses in alloys is being made. In the general programme for this study, the cobalt–chromium binary system was taken as the starting point. Cobalt-base alloys containing up to 50% of chromium, will be prepared and examined by X-ray diffraction, metallographic, dilatometric, magnetic and chemical methods to identify the phases in these alloys. The effect of heat-treatments on the microstructures will be investigated. The temperatures of the ε–β transformation will be determined and compared with those reported in the literature. After studying the binary cobalt–chromium system, alloys with iron, carbon, nickel, molybdenum, and tungsten additions will be made and studied.

High-Hydrogen Atmosphere Intensifies Quench Cracking Tendency. C. A. Liedholm. (Metal Progress, 1947, vol. 51, Mar., pp. 414–419). An account is given of an investigation into the cause of quench-cracking in hollow chromium–nickel–molybdenum steel propeller blades. Round and square notched test-pieces were quenched after heating in "Monogas" (8·5% of hydrogen) and 100%-hydrogen atmospheres. The most drastic quenching failed to crack the "Monogas" specimens, whereas all the specimens quenched in water immediately after heating in hydrogen cracked within 24 hr. Further tests showed that a delay of 3 min. before quenching was required to eliminate the cracking of propeller blades. An example is described in which an epidemic of quenching cracks was found to be caused by variations in the composition of the burnt-town-gas atmosphere.—C. O.

Absorbed Gases in Cast Iron. E. V. Somers and D. W. Gunther. (Foundry, 1947, vol. 75, Mar., pp. 66–69, 218–228). Investigations are described in which the effect of the tapping temperature of cupola iron on the chemical composition and physical properties of the cast metal was determined. Tensile strength and depth of chill were found to vary with the tapping temperature. The increase in chill formation is attributed to the increased oxidation of iron which took place as the tapping temperature was decreased. The effect of hydrogen absorption on physical properties is also discussed.—C. O.

Boron in Medium Carbon Steel. G. P. Contractor and J. S. Vatchagandhy. (Metal Treatment, 1947, vol. 14, Spring Issue, pp. 3–19). A study was made of the effect of up to 0·01% of boron on the hardenability and other properties of a series of 0·45%-carbon steels. The additions of boron progressively increase the hardenability, but the increase obtained with 0·003% to 0·007% was not so great as that reported in other papers. From 0·003% to 0·007% increased the resistance of the steels to acids and atmospheric attack, but the resistance did not increase with additions of more than 0·007%.—R. A. R.

A Survey of German Research and Development Work on Titanium. (British Intelligence Objectives Sub-Committee, Final Report No. 1179: H.M. Stationery Office).

The Use of Alloys for Imparting Corrosion Resistance to Iron and Steel. E. A. Tice. (Steel Processing, 1947, vol. 33, Apr., pp. 211–215). The effects of copper, phosphorus, silicon, nickel, chromium, molybdenum, columbium, and titanium on the corrosion-resistance of steel are discussed.—R. A. R.

Corrosion-Resisting Steel for Marine Conditions. (British Steelmaker, 1947, vol. 13, May, p. 258). As a result of extended and comprehensive trials involving exposures for periods of up to 17 years, a special type of chromium-bearing corrosion-resisting steel is recommended for use in marine atmospheres or for structures completely immersed in sea or tropical river waters.—J. R.

"Hot Hard" High Speed Steel. H. G. Johnstin. (Steel, 1947, vol. 120, Apr. 21, pp. 98–100). The properties of a new high-speed steel (with carbon 1·5%, vanadium 5%, and sufficient cobalt to improve the hot-hardness properties) are described.—C. O.

Heat Treatment of High Speed Steels. H. E. Boyer. (Steel, 1947, vol. 120, Mar. 3, pp. 110–113, 138–140; Mar. 10, pp. 92–95, 120–126). An account is given of a comprehensive investigation of the properties and heat-treatment characteristics of three types of high-speed steel, namely, the 18/4/1 tungsten–chromium–vanadium steel, the 6·5/5/4/2 tungsten–molybdenum–chromium–vanadium steel, and the 12/4/5·5/4/1 cobalt–tungsten–molybdenum–chromium–vanadium steel.—R. A. R.

Steels and Plastics. E. T. Gill and G. N. Gee. (Iron and Steel, 1947, vol. 20, May, pp. 185–188). The requirements of steels intended for use in the manufacture of moulds for the plastics industry are discussed.—J. R.

A New Magnetic Alloy. (Machinery, 1947, vol. 70, May 8, p. 490). **New High Magnetic Alloy Anneals by Quenching.** (Machinist, 1947, vol. 90, Apr. 26, p. 2155). A brief description is given of the working and heat-treatment of a new 35% cobalt, 64% iron, 1% chromium alloy, developed for use in motors and generators in aircraft by Westinghouse Research Laboratories, and known as "Hiperco." The alloy gives the highest magnetic saturation point of any known material, and for most applications a thickness of about 0·005 in. is suitable, but it may be reduced to 0·002 in. if required.—R. L. B.

How to Select and Treat Mold Steels. R. J. Hoensheid. (Machinist, 1947, vol. 91, May 3, pp. 24–26). The selection of available steels for making moulds for plastics is discussed, and treatments to avoid surface defects, *viz.*, discoloration, scaling, "orange-peel effect," and pitting, which are due to the presence of moisture during the carburizing stage in the process of manufacture, are recommended.—R. L. B.

Where to Use Low-Alloy, High-Strength Steels. H. S. Wharen. (Machinist, 1947, vol. 90, Apr. 19, pp. 2122–2125). A report is given on the use of low-alloy, high-strength steel. These steels owe their superior characteristics to properly balanced chemical composition and rolling technique. A list of proprietary brands together with their compositions and mechanical properties is shown, and reference is made to their corrosion resistance, cold and hot workability, and weldability.—R. L. B.

Aluminium Coated Steel. (Steel, 1947, vol. 120, Mar. 31, pp. 80–81, 102–104). The corrosion resistance, heat reflectivity and mechanical and welding properties of "Aluminized" steel (steel sheet coated with aluminium by a hot-dip process) are described.—R. A. R.

Present Trends in Alloys. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Mar., pp. 25–26). A short summary is made of recent developments in the industrial use of alloy steels and cast irons.—C. O.

Japanese Metallurgical Research in Fields Allied to Those of U.S. Ordnance. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./403: H.M. Stationery Office). The principal metallurgical researches in Japan were directed towards the utilization of low-grade raw materials and the development of substitute alloys for nearly all the common industrial metals. No instance of a substitution resulting in both technical and economic improvements has been found.—C. O.

Metallurgical Examination of Two Japanese 140 mm. Naval Projectiles. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1452 : H.M. Stationery Office).

Metallurgical Examination of 5-inch Japanese Naval Projectile. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1453 : H.M. Stationery Office).

Metallurgical Examination of Japanese Army 47 mm. H.E. Projectiles. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1454 : H.M. Stationery Office).

Progress Report on Examination of Enemy Material : Metallurgical Study of Two Samples of Japanese Welded Homogeneous Light Armor. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1474 : H.M. Stationery Office).—R. A. R.

Progress Report on Examination of Enemy Material : Metallurgical Examination of a Japanese Droppable Fuel Tank. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1502 : H.M. Stationery Office). One unusual alloy was found—a flange of alloy steel of composition carbon 0·40%, silicon 1·5%, chromium 1%, and molybdenum 0·25%, quenched and tempered to a hardness of 257 Vickers. —M. A. V.

Progress Report on Examination of Enemy Material : Metallurgical Examination of a Japanese 7·92 mm. Type 98 Flexible A/C Machine Gun. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1503 : H.M. Stationery Office).—R. A. R.

Progress Report on Examination of Enemy Material : Metallurgical Examination of Japanese 75 mm. Anti-Aircraft H.E. Shell with Fuse. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1505: H.M. Stationery Office). A Japanese 75-mm. high-explosive projectile was found to be forged from a silicon-killed basic-open-hearth steel, of good mechanical and physical properties, similar to S.A.E. 1050.—C. O.

Flame Hardened Steel. S. T. Jazwinski. (Steel, 1947, vol. 120, May 12, pp. 108–109, 146). Details are given of a new steel called " E-4 " containing 0·70–1·10% of copper to depress the A_3 point, with the result that it can be flame-hardened without water-quenching, air-cooling being sufficient.—R. A. R.

Developments in Aircraft Materials and Processes. P. E. Lamoureux. (Transactions of the Canadian Institute of Mining and Metallurgy, 1947, vol. 50, pp. 104–126). Recent developments in ferrous and non-ferrous alloys, wood, plastics, adhesives, fuels, and lubricants for aircraft are reviewed.—R. A. R.

Nodular Cast Iron. (Machinery, 1947, vol. 70, Apr. 24, p. 420). As a result of persistent research by the British Cast Iron Research Association, a method of treating hematite pig iron so as to obtain properties equal to those of present-day high-duty cast irons, without the necessity for special compositions or treatments, and without adversely affecting the casting and machining characteristics has been developed. The new process produces castings of cast iron having nodular or spherical graphite instead of the stringy, flaky structure usually found. Hematite test-pieces containing 3·9% of carbon, and 2·6% of silicon, showed tensile strengths of 15·5 and 26·5 tons/sq. in. in the treated and untreated conditions, respectively. The tensile strength of Ni-Resist iron may be improved from 10 to 20–25 tons/sq. in., and its shock resistance from 30 to 120 ft./lb.—R. L. B.

Iron Powder. (Iron and Steel, 1947, vol. 20, Apr., p. 136). The properties of a new high-quality hydrogen-annealed Swedish sponge-iron powder now on the market are discussed.—J. R.

METALLOGRAPHY

The Metallurgical Microscope—Its Range and Use. D. E. Roda. (Iron Age, 1947, vol. 159, Feb. 20, pp. 53–55). Six photomicrographs of the same area of a steel specimen, taken at magnifications of 115 to 3900, are presented and discussed to illustrate the working range of the metallurgical microscope.—C. O.

The Electron Optical System of the Electron Microscope. M. E. Haine. (Journal of Scientific Instruments, 1947, vol. 24, Mar., pp. 61–66). Some theoretical and practical considerations in the design and use of the electron microscope are considered and the electron optical components are described. The procedure for aligning the Metrovik instrument type E.M.2 is given.—R. A. R.

The Electron Microscope. J. R. Davy. (Iron and Coal Trades Review, 1947, vol. 154, Apr. 11, pp. 623–627). With the aid of the electron microscope details of fine structure have been revealed which, for theoretical reasons, will always lie beyond the powers of the optical microscope. A survey is made of the principles underlying the development of the instrument and its construction, and an account is given of industrial applications made up to the present time.—J. R.

The Electron Microscope. H. J. de Heer. (Metalen, 1947, vol. 1, Feb., pp. 101–104). (In Dutch). The principles of the electron microscope are explained and a description is given of the instrument at the Netherlands Institute for Electron Microscopy at Delft.—R. A. R.

The Importance of the Electron Microscope in Investigations of Metals. H. C. J. De Decker. (Metalen, 1947, vol. 1, Mar., pp. 113–117 ; Apr., pp. 139–144). (In Dutch). The limits of the resolving power of the electron microscope are discussed and the different techniques by which it can be applied to study metals are described. —R. A. R.

The Design and Construction of a New Electron Microscope. M. E. Haine. (Institution of Electrical Engineers, 1947, Preprint). Starting from the limitations to the resolving power of the optical microscope, the discovery of de Broglie concerning the wave aspect of moving particles and the derivation of the electron lens by Busch are described. The limiting action of the spherical aberration of the electron lens is discussed and the theoretical limit set by this and diffraction effects is evaluated as 10Å. The function and requirements of the various parts of a practical instrument are discussed and a description is given of the new instrument designed by the author and his collaborators.—R. A. R.

Conditions for Extending the Resolution Limit of the Electron Microscope. V. E. Cosslett. (Journal of Scientific Instruments, 1947, vol. 24, Feb., pp. 40–43). The limiting resolution obtainable with magnetic lenses may be reduced below 10Å by using a sufficiently high accelerating voltage, provided that the lens power is maintained at an optimum value which gives minimum aberration. This may be achieved either by increasing simultaneously the strength of the magnetic focusing field in a lens of fixed dimensions, or by increasing lens dimensions at a given value of field strength. In either case a resolving limit of 5 to 6Å is predicted.—R. A. R.

A New Method of Electrolytic Polishing of Electron Microscope Samples. E. Der Mateosian. (Iron Age, 1947, vol. 159, Jan. 16, pp. 51–53). A method for the electrolytic polishing of metal samples for examination

with the electron microscope is described. A high current density (up to 1 amp./sq. cm.) and a carefully adjusted acidity are required. It has been found that chilling of the anodic sample increases the *p*H range within which polishing takes place.—C. O.

Polishing of 0·60 Carbon Steels. C. P. Kenyon. (Metal Progress, 1947, vol. 51, Feb., pp. 260–261). Description of the polishing of metallographic specimens is given—R. A. R.

Mounting for Edge Examination. A. Hone. (Metal Progress, 1947, vol. 51, Mar., pp. 435–437).

Macrographic and Micrographic Study of Steel Plates Rolled from Large Ingots. H. Malcor. (Bulletin of the Société Française de Métallurgie, 1945, Jan.–June, pp. 31–44; Revue de Métallurgie, 1945, vol. 41, Aug., pp. 241–253). Ingots of nickel–chromium steel weighing 30–60 tons and from 550 to 1000 mm. in thickness were rolled into plate 38 to 50 mm. thick. At 1000 magnifications, five distinct types of inclusion were observed which are described in detail with photomicrographs. Analysis showed that they consisted, respectively, primarily of alumina, silicon-rich silicates and possibly chromium oxide; silicates; sulphides; manganese-rich silicates; and spinel ($FeO.Cr_2O_3$). A very approximate estimation of their amounts by volume was made from which total contents in the inclusions of 0·013% of sulphur, 0·0015–0·020% of oxygen and 0·001–0·003% of aluminium, based on the steel, were obtained. Bending tests showed that inclusions of the first type were undoubtedly responsible for the formation of hair-line cracks.—R. A. H.

Japanese Metallurgy. Atomic Structure Relative to Dynamic Properties. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./579: H.M. Stationery Office). This report covers Japanese research in the field of atomic and crystal structure in relation to dynamic properties such as strength, ductility and brittleness.—R. A. R.

A Model Which Shows Hardening and Annealing Mechanisms. E. C. Davis. (Metal Progress, 1947, vol. 51, Feb., pp. 248–249). A simple method of demonstrating the changes in the atomic structure of metals caused by heating, hardening, and cold-work is described. It consists of changing the arrangement of small lead shot in a watch glass.—R. A. R.

Determination of Austenite Grain Size in Cast Steels. M. F. Hawkes. (Iron Age, 1947, vol. 159, Mar. 13, pp. 46–51). Methods of determining the grain size of the low temperature are described. Micrographs of aluminium-killed and silicon-killed cast steels are shown. —R. A. R.

Study of the Iron–Silicon Diagram up to 30% Silicon from the Viewpoint of Practical Applications. A. Weill. (Revue de Métallurgie, 1945, vol. 42, Aug., pp. 266–270). This is a slightly abridged French translation of the paper "An X-Ray Study of Iron-Rich Iron–Silicon Alloys," by M. C. M. Farquhar, H. Lipson and A. R. Weill. (*See* Journ I. and S. I., 1945, No. II, p. 457P).—R. A. H.

CORROSION

Corrosion Ratings for Metals. H. D. Holler and R. A. Frye. (Corrosion, 1947, vol. 3, Jan., pp. 8–22). The factors to take into account when predicting the probable corrosion-resistance of a material under given conditions are discussed and three tables are presented giving corrosion ratings for (*a*) magnesium, aluminium, and their alloys, (*b*) alloys of iron, nickel, and chromium, and (*c*) a copper and copper alloys. It is shown to be impossible to assign values to the corrosion resistance of metals *per se*, and the tables relate to the behaviour of the materials in rural, urban, and marine atmospheres, as well as in industrial atmospheres containing NH_3, H_2S, HCl, SO_2, or chlorine.—R. A. R.

Investigation of Electrolytic Corrosion of Steel in Concrete. (Association of American Railroads: Corrosion, 1947, vol. 3, Jan., pp. 37–54). This is the Third Progress Report of the Committee on Electrolysis which has been investigating the corrosion of steel in concrete. It describes a special test to determine the resistance to earth, amount of current flow, and corrosion of steel embedded in different thicknesses of concrete. Increasing the thickness of concrete surrounding the reinforcing bars reduced the rate of electrolytic corrosion, but did not eliminate it and prevent cracking of the concrete. An asphalt membrane waterproof covering on the concrete effectively prevented the electrolytic corrosion of the steel and the deterioration of the concrete. In an appendix L. S. Brown describes the effect of electric current on concrete.—R. A. R.

Sheet Pile Corrosion at Port of Copenhagen. M. Blach and A. Rogberg. (Engineer, 1947, vol. 183, Apr. 25, pp. 348–350). The results of investigations into the corrosion of steel sheet piles in two wharves, built in Copenhagen harbour in 1916 and 1917, are presented. The heaviest corrosion was found in a belt 0·35–0·50 m. below the mean water level. The corrosion at water level is not great, and at depths below 2 m. there is practically none. The webs of the trough-shaped piles were more heavily corroded than the legs. The maximum annual corrosion is estimated at 0·20 mm.—C. O.

Corrosion and Protection against Corrosion at the Present Time. W. Wiederholt. (Technik, 1947, vol. 2, Mar., pp. 122–125). Modern methods of protecting metals against corrosion are reviewed with special reference to those most suitable for use in Germany today.—R. A. R.

Long-Time Natural Corrosion Tests on Various Constructional Steels in Air and in Different Sea and River Waters. Part 1. General Organization of the Test and Description of the Test Specimens. H. Bandot. **Part 2. Test Procedure, Interpretation of Results, Conclusions.** G. Chaudron. (Revue de Métallurgie, 1946, vol. 43, Jan.-Feb., pp. 1–67). Specimens of 24 different steels were exposed to atmospheric or marine corrosion from 1938 to 1943 at nine localities in France. In Part 2, the author refers to his earlier paper describing preliminary tests (*see* Journ. I. and S.I., 1939, No. II, p. 178A) and then gives full details of the results of the present investigation with a critical discussion of the analytical methods used. It is considered that tests for one year are sufficient.—R. A. H.

Resistance of Some Nickel-Containing Alloys to West Texas Crudes. B. B. Morton. (Corrosion, 1947, vol. 3, Jan., pp. 23–34). The corrosive agents in West Texas oil production are primarily sulphur in the form of H_2S and organic sulphides that are changed into H_2S during refining operations. At above 500° F. during refining, attack is best resisted by the nickel-bearing high-chromium steels, whilst in the production of crudes at below 500° F., nickel, Monel, Inconel and the high-alloy cast irons are very resistant as the corrosion is of the electrolytic instead of the dry type. Examples of

pumping equipment, "sucker rods" and tubes in the new and corroded state are discussed. The properties and compositions of the nickel steels and other nickel alloys are given.—R. A. R.

The Chaney-Barnes Internal Tubing Caliper and Notes on its use. P. E. Chaney. (Corrosion and Material Protection, 1947, vol. 4, Jan.–Feb., pp. 11–14). The construction and method of operation of a mechanical tool is illustrated and described. It was designed specially for measuring the extent and location of corrosion damage in gas-well tubing *in situ*. The caliper may be calibrated to measure the depth of corrosion pits with an accuracy of ± 0·01 in. and the instrument also produces a chart of the changes in corrosion along the tube wall. Examples of these are shown.—N. S.

Intergranular Corrosion Determination. H. Kirtchik. (Iron Age, 1947, vol. 159, Mar. 6, pp. 67–70). A procedure is described for evaluating the sensitivity of stainless steel and Inconel to intergranular corrosion when heated in gases containing lead halides. The tests were part of an investigation of the failure of aeroplane supercharger nozzle boxes.—R. A. R.

Measurement of Corrosion Pits in Boiler Tubes. B. M. Thornton. (Engineering, 1947, vol. 163, Mar. 28, pp. 229–230). An illustrated description is given of an instrument for measuring the changes in the wall-thickness of boiler tubes. It consists of an exploring head with an iron core on which a primary coil is mounted between two opposed secondary coils. The head is inserted in a good portion of the tube and the micro-ammeter is set at, or near, its maximum reading. The head is made to traverse the tube and changes in the thickness of the wall produce an out-of-balance e.m.f. in the secondary coils which is applied to a metal rectifier, the output being measured on the micro-ammeter.—R. A. R.

The Prevention of Corrosion by Fluorine and by Hydrofluoric Acid Requires Special Apparatus. M. G. Fontana. (Industrial and Engineering Chemistry, 1947, vol. 39, Mar. 14, pp. 91A–92A). Various ferrous and non-ferrous metals and alloys and non-metallic materials resistant to dry and moist fluorine and to hydrofluoric acid in various concentrations are briefly discussed.—D. R. S.

ANALYSIS

Two Years' Progress in the Analysis and Testing of Solid Fuel. A. H. Edwards. (Monthly Bulletin of the British Coal Utilisation Research Association, 1947, vol. 11, Mar., pp. 69–75). This is a review of the work of various investigators on the analysis and testing of coal and coke. A bibliography of 58 references to the literature on the subject is appended.—R. E.

Determination of Manganese in Iron Ores. E. R. Bechtel, jun., and W. G. Crowle. (Chemist Analyst, 1947, vol. 36, Feb., pp. 4–8). A reliable routine method for the determination of manganese in iron ores has been developed. After dissolving the ore in a mixture of phosphoric and sulphuric acids the manganese is oxidized to permanganate by silver nitrate and ammonium persulphate, and titrated with a standard sodium-arsenite/sodium-nitrite solution.—D. R. S.

Methods of Analysis of Chromium Plating Solutions. F. W. Salt. (Armament Research Department: Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 15–18). An account is given of the estimation of chromic acid, trivalent chromium, and iron in plating solutions by a method taking only 1½ hr.—C. O.

Estimation of Nickel, Cobalt, Chloride, Formate and Formaldehyde in Nickel–Cobalt Plating Solutions. F. W. Salt. (Armament Research Department: Journal of the Electrodepositors' Technical Society, 1947, vol. 22, pp. 19–21). Details are given of volumetric methods for the analysis of nickel–cobalt plating solutions.—C. O.

Polarographic Determination of Vanadium in Steel and Other Ferroalloys. J. J. Lingane and L. Meites, jun. (Analytical Chemistry, 1947, vol. 19, Mar. 25, pp. 159–160). A method is described for the polarographic determination of vanadium in steel and other ferrous alloys after the removal of interfering elements from a dilute sulphuric-acid/phosphoric-acid solution with a mercury cathode. In the subsequent polarographic determination the anodic diffusion current produced by the oxidation of tetravalent to pentavalent vanadium in the presence of sodium hydroxide and sodium sulphite is measured. The average error for alloys containing between 0·01% and 2% of vanadium was found to be only 0·005%.—D. R. S.

Emission Spectroscopy and Some of Its Industrial Applications. J. E. Scott. (Steel Processing, 1947, vol. 33, Apr., pp. 216–218).

BOOK NOTICES

ALLAN, R. K. "*Rolling Bearings.*" Second Edition, 8vo, pp. xiv + 401. Illustrated. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 30*s.*). This is the second edition of a treatise covering the history, design and the practical application and use of ball and roller bearings.—R. E.

AMERICAN SOCIETY FOR METALS. "*Heat Treatment of Metals.*" A Series of Educational Lectures presented to Members of the Los Angeles Chapter of the Society. 8vo, pp. 178. Illustrated. Cleveland, Ohio, 1946: The Society. (Price 18*s.*).

This book contains the following papers: Why Heat Treat? by E. Brooker; How Heat Treat? by G. B. Berlien; Results from Heat Treatment, by G. M. Huck; Why Does Steel Harden? by E. R. Mertz; Hardenability, by W. F. Nash, jun.; Practical Applications and Use of Hardenability, by E. E. Fess; Induction Heating, by H. B. Osborn, jun.; Isothermal Transformation in Steel, by E. S. Davenport; Improved Treatments of Aluminium Alloys, by M. E. Tatman; Practical Application of Heat-Treated Light Metal Alloys, by S. R. McBride.—R. E.

DE MILLE, J. B. "*Strategic Minerals.*" 8vo, pp. viii + 626. First Edition. New York, 1947: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 37*s.* 6*d.*).

Information is given on the properties, uses, American sources of supply and production, the world's production, and American imports and exports of seventy-six strategic metals and minerals.—R. E.

DE SY, A. "*Algemene Metallurgie.*" (Leerboek der Algemene Metallurgie, Siderurgie, Electrosiderurgie en Metallografie, Deel 1). 8vo, pp. 248. Illustrated. Antwerpen, 1947: Uitgeversmij. N. V. Standaard Boekhandel.

Professor De Sy, Director of the Department of Metallurgy and Metallography at the University of

Ghent, is the author of this general treatise on metallurgy. Volume I, which has been recently published, deals with general physico-chemical principles, general metallurgical principles, metallurgical processes, fuels and their metallurgical applications, metallurgical furnaces and refractory materials.—R. E.

MACKENZIE, COMPTON. "*The Vital Flame.*" 4to, pp. 80. Illustrated. London, 1947 : British Gas Council. (Price 12*s.* 6*d.*).

Compton Mackenzie surveys the historical past, the progressive present, and the future importance of the British gas industry. The book looks back to the 18th century, when William Murdoch lighted his Redruth Cottage with gas.—R. E.

STEINER, K. "*Fuels and Fuel Burners.*" First Edition. 8vo, pp. xi + 394. Illustrated. New York, 1946 : McGraw-Hill Book Co., Inc. ; London : McGraw-Hill Publishing Co., Ltd. (Price 22*s.* 6*d.*).

This book deals with the nature, occurrence and properties of fuels from the viewpoint of domestic and commercial heating, and the design, installation and operation of stokers, oil burners, and gas burners. A discussion is included of automatic control methods and apparatus for heating systems, including conventional electrical types and the more recent electronic developments. A chapter on wood fuel is also included. —R. E.

YOUNG, C. B. F., and K. W. COONS. "*Surface Active Agents.*" 8vo, pp. x + 381. Brooklyn, 1945 : Chemical Publishing Co., Inc.

The theoretical aspects of surface tension, its application to industrial fields, effects of surface-active agents, and the relation between surface tension and other physical properties of matter are dealt with. The book also deals with diverse branches of industry in which surface active agents are used, and contains typical formulæ which will facilitate the formulation of emulsions and other products based on the utilization of surface-active agents. Methods and apparatus for the determination of surface tension are described and illustrated, and an alphabetical list of wetting and other surface-active agents, giving the composition, uses, and names of American manufacturers, is included.—R. E.

NEW PUBLICATIONS

AGEEV, N. V. "*The Nature of the Chemical Bond in Metallic Alloys.*" [In Russian.] 8vo, pp. 120. Illustrated. Moscow and Leningrad, 1947 : Izdatel'stvo Akademii Nauk S.S.S.R. (Price 6 roubles).

AMERICAN IRON AND STEEL INSTITUTE. Contributions to the Metallurgy of Steel, No. 12. "*Calculation of the Standard End-Quench Hardenability Curve from Chemical Composition and Grain Size.*" 8vo, pp. 25. Illustrated. New York 1, N.Y., 1946 : The Institute.

AMERICAN IRON AND STEEL INSTITUTE. Contributions to the Metallurgy of Steel, No. 13. "*The Development of Steel Kegs.*" 8vo, pp. 112. Illustrated. New York 1, N.Y., 1946 : The Institute.

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AMERICAN IRON AND STEEL INSTITUTE. Contributions to the Metallurgy of Steel, No. 16. "*Mechanical Testing Procedures and Definitions for Plates and Structural Sections.*" 8vo, pp. 19. Illustrated. New York 1, N.Y., 1947 : The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Testing Parts and Assemblies.*" Sponsored Jointly by American Society for Testing Materials and Society for Experimental Stress Analysis. 8vo, pp. 86. Philadelphia, 1946 : The Society.

BALDI, E. "*Microfotografia e Macrofotografia.*" Pp. xii + 352. Illustrated. Milan, 1946 : Ulrico Hoepli. (Price L.900).

BENEDICT, O. J., jun. "*Manual of Foundry and Pattern-Shop Practice. Parts I and II.*" New York, 1947 : McGraw-Hill Book Co., Inc.

BRITISH STANDARDS INSTITUTION. B.S.325 : 1947. "*Black Cup and Countersunk Bolts, Nuts, and Washers.*" 8vo, pp. 15. London, 1947 : The Institution. (Price 2*s.* 0*d.*).

BROKEN HILL PROPRIETARY CO., LTD. "*Staff Training Handbook.*" Sm. 8vo., pp. 133. Newcastle, N.S.W., 1947.

CALLANDREAU, E. "*Problèmes de Résistance des Matériaux avec leurs Solutions.*" 8vo, pp. 524. Illustrated. Paris, 1944 : Albin Michel, 22, Rue Huyghens. (Price 410 francs).

DE MILLE, J. B. "*Strategic Minerals.*" 8vo, pp. viii + 626. First Edition. New York, 1947 : McGraw-Hill Book Co., Inc. ; London : McGraw-Hill Publishing Co., Ltd. (Price 37*s.* 6*d.*).

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IRON AND STEEL INSTITUTE. Special Report No. 38. "*Symposium on Powder Metallurgy.*" 4to, pp. 208. Illustrated. London, 1947 : The Institute. (Price 16*s.*, Members 10*s.*).

KUNITZ, H. A. "*Oil Burning Handbook.*" Third Edition, revised. 8vo, pp. 464. Illustrated. Philadelphia and London, 1947 : J. B. Lippincott. (Price $5.00).

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SMART, R. C. "*The Technology of Industrial Fire and Explosion Hazards.*" Vols. 1 and 2. 8vo, pp. 202 + 184, London, 1947 : Chapman and Hall, Ltd. (Price 16*s.* each).

STEEL FOUNDERS' SOCIETY OF AMERICA. "*Directory of Steel Foundries in the United States and Canada.*" 1946, 8vo, pp. 177. Cleveland, Ohio : The Society (Price £3).

TOLANSKY, S. "*High Resolution Spectroscopy.*" Pp. xi + 291. London : Methuen and Co., Ltd. (Price 21*s.*).

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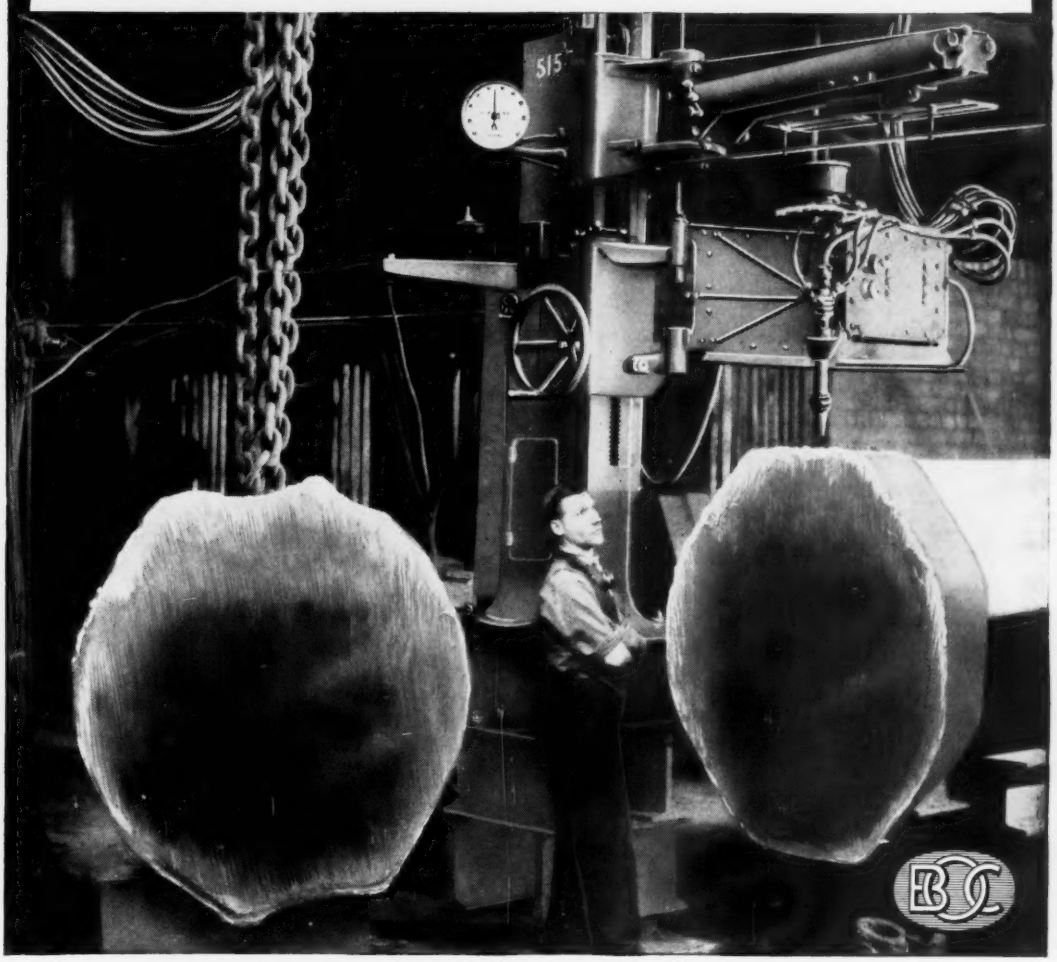

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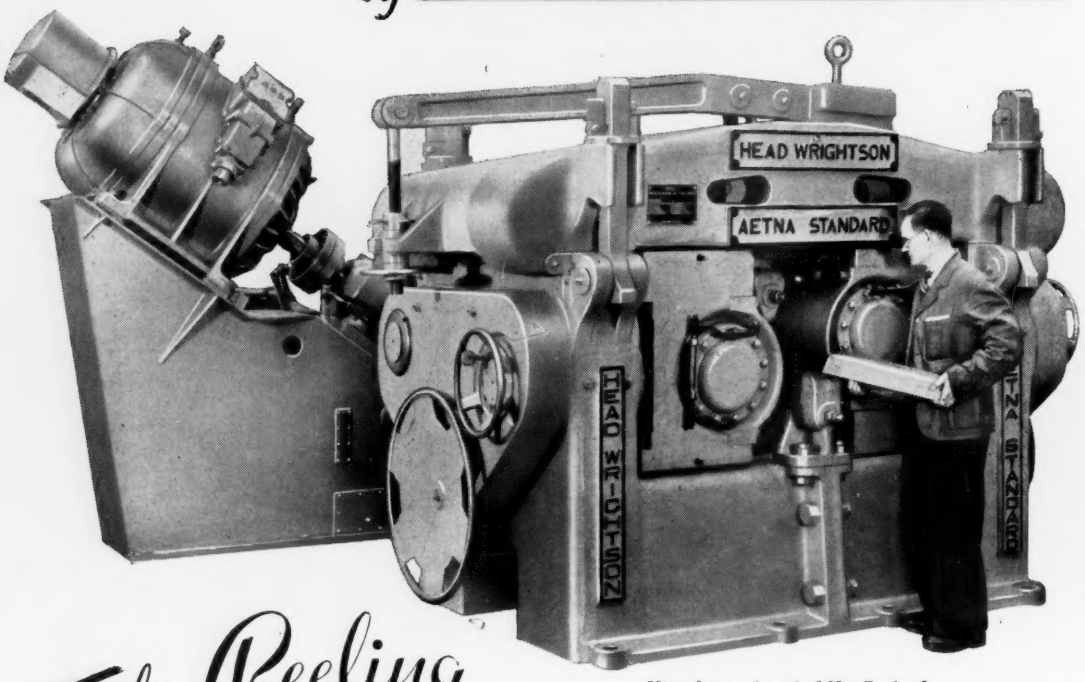

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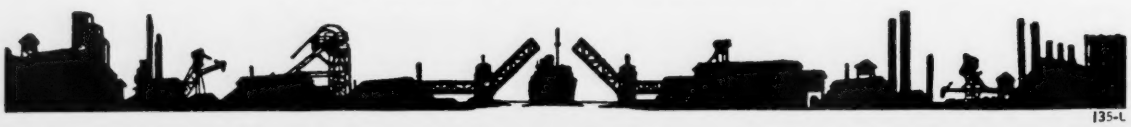

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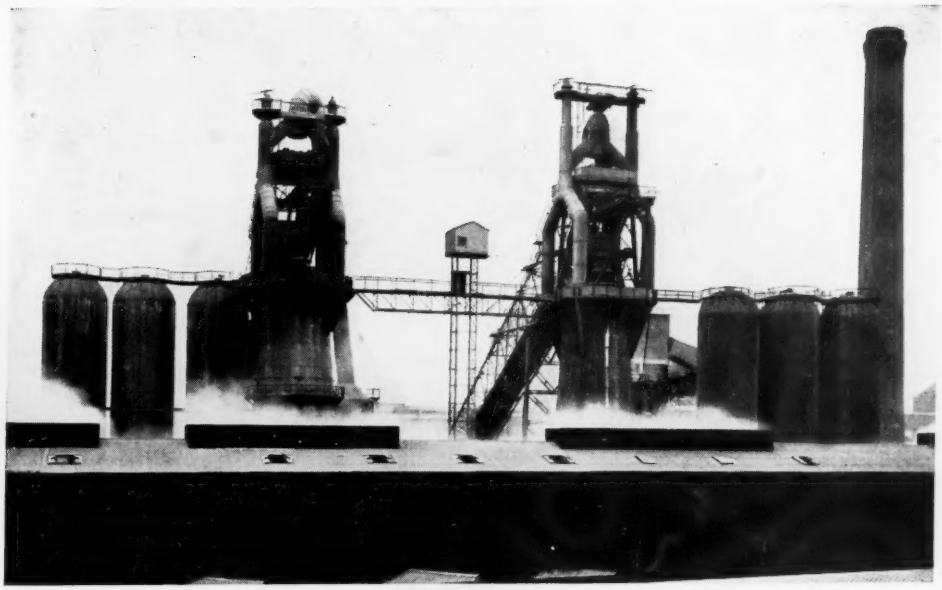

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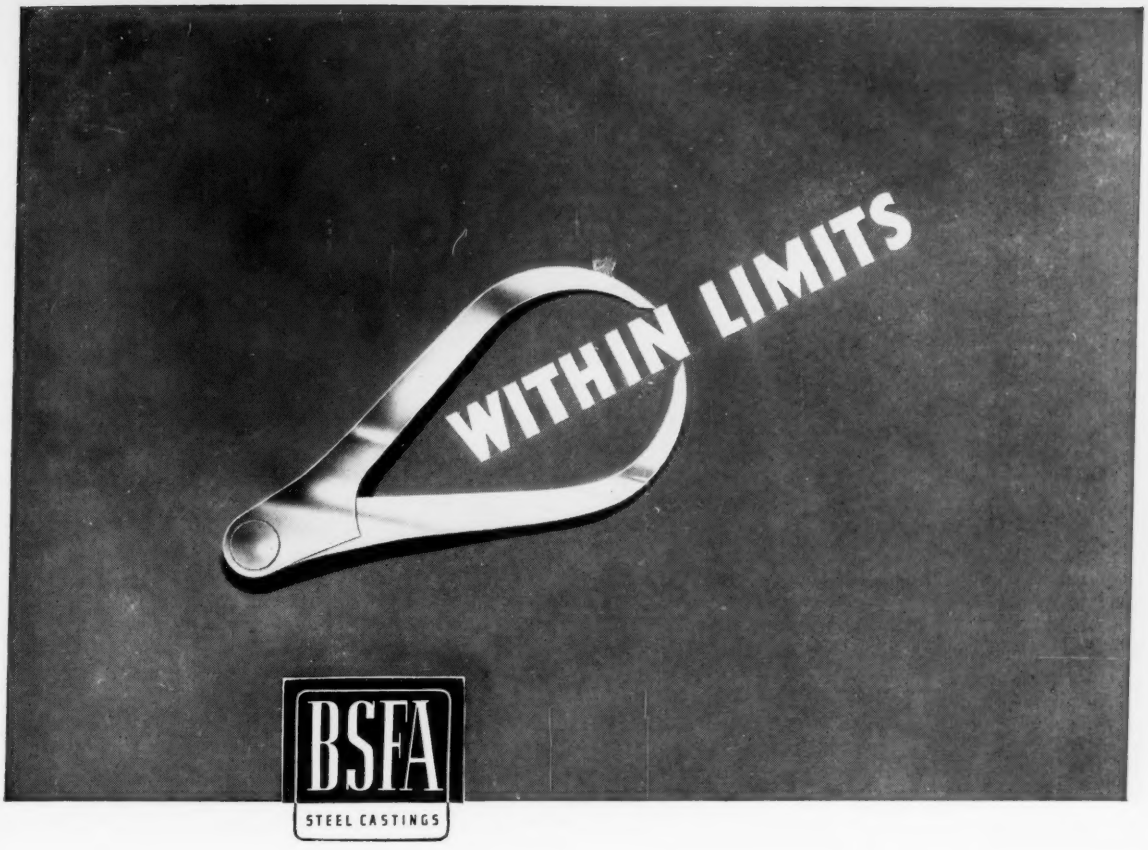

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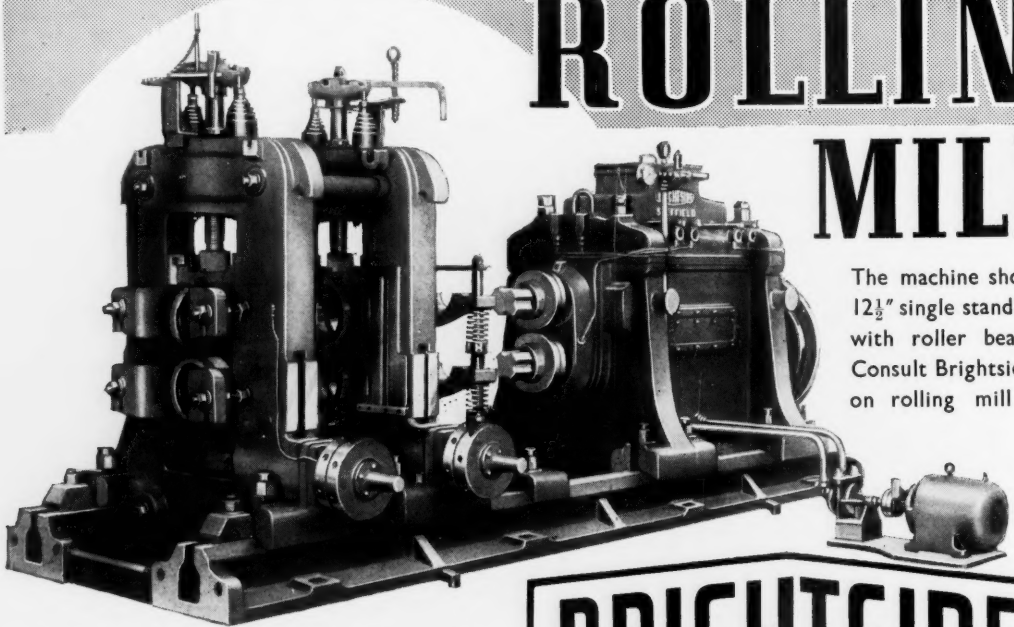

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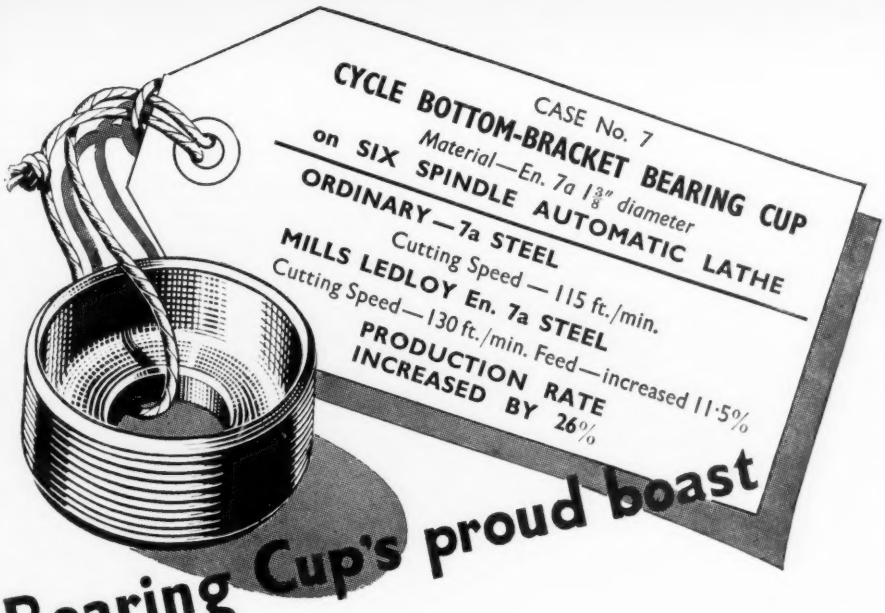

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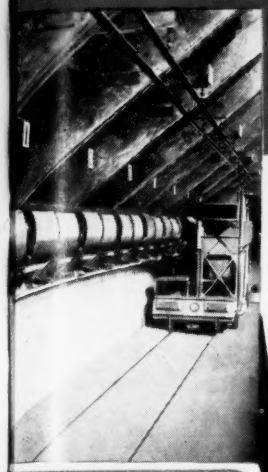
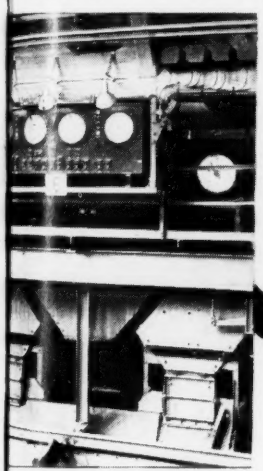
THE PRIME ESSENTIALS OF BLAST FURNACE CHARGING



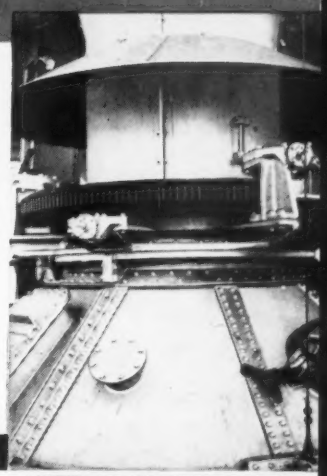
1. ORE AND LIMESTONE ARE COLLECTED AND CORRECTLY WEIGHED.



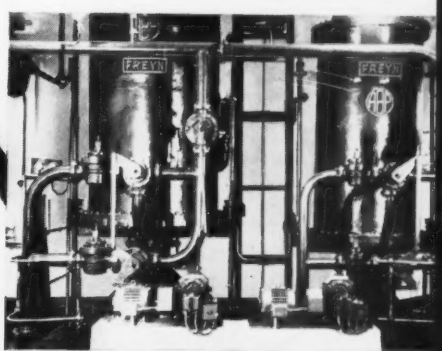
2. COKE IS SCREENED AND WEIGHED VOLUMETRICALLY MEASURED.

3. SKIP ELEVATES MATERIALS TO THE FURNACE TOP.

FREYN DESIGN
ABP ENGINEERING

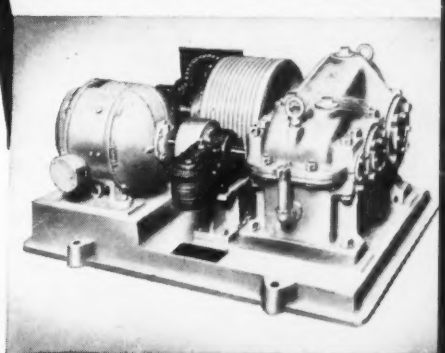


4. MATERIALS ARE CORRECTLY DISTRIBUTED ON THE LARGE BELL.



5. THE SMALL AND LARGE BELL ARE DUMPED IN THE CORRECT SEQUENCE.

7. THE WHOLE IS INGENIOUSLY SEQUENCED AND INTERLOCKED AT THE CENTRAL CONTROL PANEL OPERATED FROM THE PANEL SEEN IN FIG. 2.



6. CONSTANT MEASUREMENT OF THE STOCK LINE IS RECORDED.

ABP

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